



Research and Technology 1994 Annual Report

John F. Kennedy Space Center



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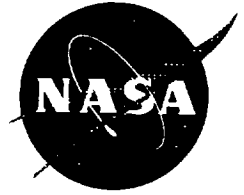
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About the Cover

The cover depicts the transfer of technology from aerospace to private industry.

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**Research and Technology
1994 Annual Report
of the John F. Kennedy
Space Center**




FOREWORD



As the NASA Center responsible for preparing and launching space missions, the John F. Kennedy Space Center is placing increasing emphasis on its advanced technology development program. This program encompasses the efforts of the Engineering Development Directorate laboratories, most of the KSC operations contractors, academia, and selected commercial industries — all working in a team effort within their own areas of expertise. This edition of the Kennedy Space Center Research and Technology 1994 Annual Report covers the efforts of these contributors to the KSC advanced technology development program, as well as our technology transfer activities.

W.J. Sheehan, Chief, Technology Programs and Commercialization Office (TPO), (407) 867-3017, is responsible for publication of this report and should be contacted for any desired information regarding the advanced technology program.


Jay F. Honeycutt
Director

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TECHNOLOGY PROGRAMS AND COMMERCIALIZATION

INTRODUCTION

In 1994 in response to the Report of the National Performance Review (From Red Tape to Results: Creating Government That Works Better and Costs Less: NASA Section), NASA published its "Agenda for Change." The agenda calls for an increased emphasis on the prompt availability of NASA technology and technical expertise to nonaerospace industry in the United States. The John F. Kennedy Space Center (KSC) has risen to this challenge by expanding efforts to identify KSC industrial customers and to provide them with mutually beneficial partnership opportunities. Efforts have been initiated to augment and streamline the Technology Transfer, Dual Use, and Patents License Programs and to develop measurements of the value of KSC technology to the U.S. economy.

TECHNOLOGY TRANSFER AND OUTREACH PROGRAM

KSC has joined with the George C. Marshall Space Flight Center (MSFC), the John C. Stennis Space Center (SSC), and the Southern Technology Applications Center (STAC) to develop a Southeast Regional Industry Outreach Partnership. The program will standardize the participating organizations' approach to metrics and will facilitate transfer and resolution of industry assistance requests within the region.

In support of the Southeast Regional Outreach Partnership, KSC is initiating an agreement with Florida Technological Research and Development Authority (TRDA) to assist in outreach to the Florida manufacturing community in early 1995. TRDA will effect the program through local Economic Development Councils, which will work closely with KSC to provide Florida industry with access to NASA technological expertise and resources in the resolution of industrial problems. The program will provide a unique resource to any Florida industry that may benefit through prompt assistance from NASA's special technological capabilities.

Existing KSC-developed technology available for commercialization is highlighted and continues to be made accessible to industry through KSC Opportunity Sheets as well as the publication *NASA Tech Briefs*. KSC Opportunity Sheets provide quick-response distribution of information on KSC developments that are determined to have commercial potential. Distribution at trade shows and to call-in or E-Mail requesters provides industry streamlined access to these opportunities.

A World Wide Web Internet Home Page for the Technology Transfer and Commercialization Programs at KSC has been established and is available at URL:<http://technology.ksc.nasa.gov>. Information on the KSC programs and staff is available through this service.

PATENT AND LICENSE PROGRAM

KSC has developed a streamlined procedure for obtaining a moderate cost, nonexclusive license of patented KSC technology. The simplified procedure is designed to maximize distribution and commercialization of NASA technology that may be of interest to multiple commercial firms. Exclusive license opportunities are also available. KSC currently has approximately 100 current patented technologies available for license.

DUAL USE PROGRAM

KSC is pursuing an expanded Dual Use Program during 1995. Projects that come under the dual use umbrella are those that develop technology into products that both meet a NASA/KSC need and have commercial opportunities. The first of these projects was a joint effort with the Department of Energy for developing an electrically conductive polymer that can be used in coating systems that protect metal from corrosion damage. This has immediate applicability to KSC operations and has potential markets wherever metal structures face the potentially harmful effects of corrosive environments.

During 1994, work proceeded on another dual use agreement to jointly develop the Universal Signal Conditioning Amplifier (USCA), which can universally connect all types of sensors and transducers to current and proposed data acquisition systems. The USCA is needed for use in KSC operations but also has applications in industry. USCA was developed by engineers at NASA KSC and I-NET Space Services, a KSC engineering support contractor. TRDA, with its commercial partner Loral Test and Information Systems, is developing the USCA. Loral is readying the amplifier for manufacture, with the first units expected to be produced in early 1995. A follow-on agreement was also signed with TRDA and Loral to jointly develop the Advanced Data Acquisition System (ADAS) to collect the digital data output of multiple USCA's.

Finally, in an agreement with TRDA, KSC is conducting a characterization study of a supersonic cleaning nozzle that is designed to be used for cleaning parts that were previously cleaned using chlorofluorocarbons. When the characterization study is complete, KSC plans to pursue a dual use partnership with a company to develop the nozzle for a number of commercial cleaning applications.

CONCLUSION

KSC will continue to augment and streamline its commercialization efforts during 1995. New ideas, new approaches, and new initiatives are essential to continue KSC's mission to best serve the American people in the current changing economic environment. KSC is open to creative approaches in technology development and research partnerships with commercial manufacturers and other governmental or nongovernmental organizations. Questions on or interest in any of the above programs should be addressed to the KSC Technology Programs and Commercialization Office at mail code DE-TPO, John F. Kennedy Space Center, Florida 32899, or call (407)867-3017, or send to E-Mail *technology:transfer:@KSC.nasa.gov*.



The Automation and Robotics effort at the John F. Kennedy Space Center (KSC) is focused on solving existing launch vehicle and payload ground processing operational problems. In addition, the program provides a forum for NASA research centers to demonstrate advanced technology for complex robotic problems that must be addressed for future space missions. Automating ground operations, in areas such as payload inspection, Shuttle tile rewaterproofing, removing and replacing flight items, and facility maintenance, enables KSC to develop procedures, processes, and methods that can be translated into solving on-orbit requirements as well as solving ground processing problems. KSC will continue to work with NASA research centers to develop the technology for increased automation of ground processing by investigating advanced collision-avoidance systems, multidegree-of-freedom robotic systems, intelligent control systems, sensors for inspection, integration of robotics with real-time data processing and information systems, and integration of robotics with advanced software techniques, such as virtual reality and knowledge-based monitoring and diagnostic systems.

Automation and Robotics

Automated Tile Processing System (ATPS) Development

The objective of this project is to design and develop a prototype system to robotically process the lower surface orbiter tiles. The project is approximately 85 percent complete. The robotic system will perform preflight and postflight inspections and rewaterproofing of 85 percent of the lower surface tiles. This is a 4-1/2-year development effort that will conclude with a demonstration of the prototype mobile robotic system in the fourth quarter of 1995. Certification testing of this system for use on orbiters will be initiated in the first quarter of 1996.

Maintenance and repair of the orbiter Thermal Protection System (TPS) tiles involve many labor-intensive tasks. As a result of a detailed orbiter TPS automation study, orbiter lower surface tile rewaterproofing and visual inspection were selected for initial robotic automation. Both of these tasks are performed on more than 20,000 tiles for each orbiter refurbishment flow. Automation of these processes is expected to save 2 to 3 weeks of TPS flow time and more than 600 labor man-hours per flow. Enhancements to robot inspection capabilities (i.e., the three-dimensional characterization of defects) will result in additional manpower savings. These savings will be realized through paperwork reductions (i.e., documentation processing) for each of the tasks automated because the robot information system will be integrated with existing data management and information processing systems. The benefits of the enhancements to inspection system capabilities have been estimated to be as high as \$60,000 per orbiter flow. This estimate is based on the average number of problem and discrepancy reports generated per orbiter flow. Quality and reliability will be improved by providing accurate first-pass inspections and rewaterproofing injections. Increased personnel safety will result because human exposure to the rewaterproofing chemical will be virtually eliminated for the lower surface tile rewaterproofing process. Long term, the RTPS is being designed to support automation of other labor-intensive TPS processes that will result in more than 2,500 direct man-hour savings per orbiter flow.

The robotic system will integrate state-of-the-art systems in navigation, control, mobility, manipulation, information management, and sensor technologies to inspect and rewaterproof the bottomside orbiter tiles in the Orbiter Processing Facility at KSC.

Key design features of the robot include: (1) a self-contained operation (i.e., no tether), (2) redundant sensors used in critical applications to ensure safe operation, (3) a 7-degree-of-freedom robot manipulator with a 3-degree-of-freedom mobile base, (4) an intuitive graphical user interface for ease of operation, and (5) interfaces to existing NASA databases.

The accomplishments for fiscal year 1994 include delivery of a prototype mobile robot from Carnegie Mellon University (CMU) and mechanical and electrical integration of the vision system and rewaterproofing tools. The software design for the mobile robot high-level controller was initiated. Evaluation of all CMU-developed software was initiated and is 40 percent complete. Evaluation and assessment of the mobile robot's mechanical and electrical systems were completed, and the redesign and modification effort was initiated. Development of the workcell controller is 95 percent complete. Funding was obtained to develop the system certification documentation for the rewaterproofing system. Formalizing the system certification requirements was initiated with the appropriate KSC and Johnson Space Center personnel.

The effort for fiscal year 1995 will focus on completing the development, integration, and testing of all subsystems into a functional robotic system. Demonstrations will occur during the year and conclude with an integrated system in November. The certification testing can be initiated after the system demonstration. It is expected the system certification will require approximately 9 to 12 months to complete.



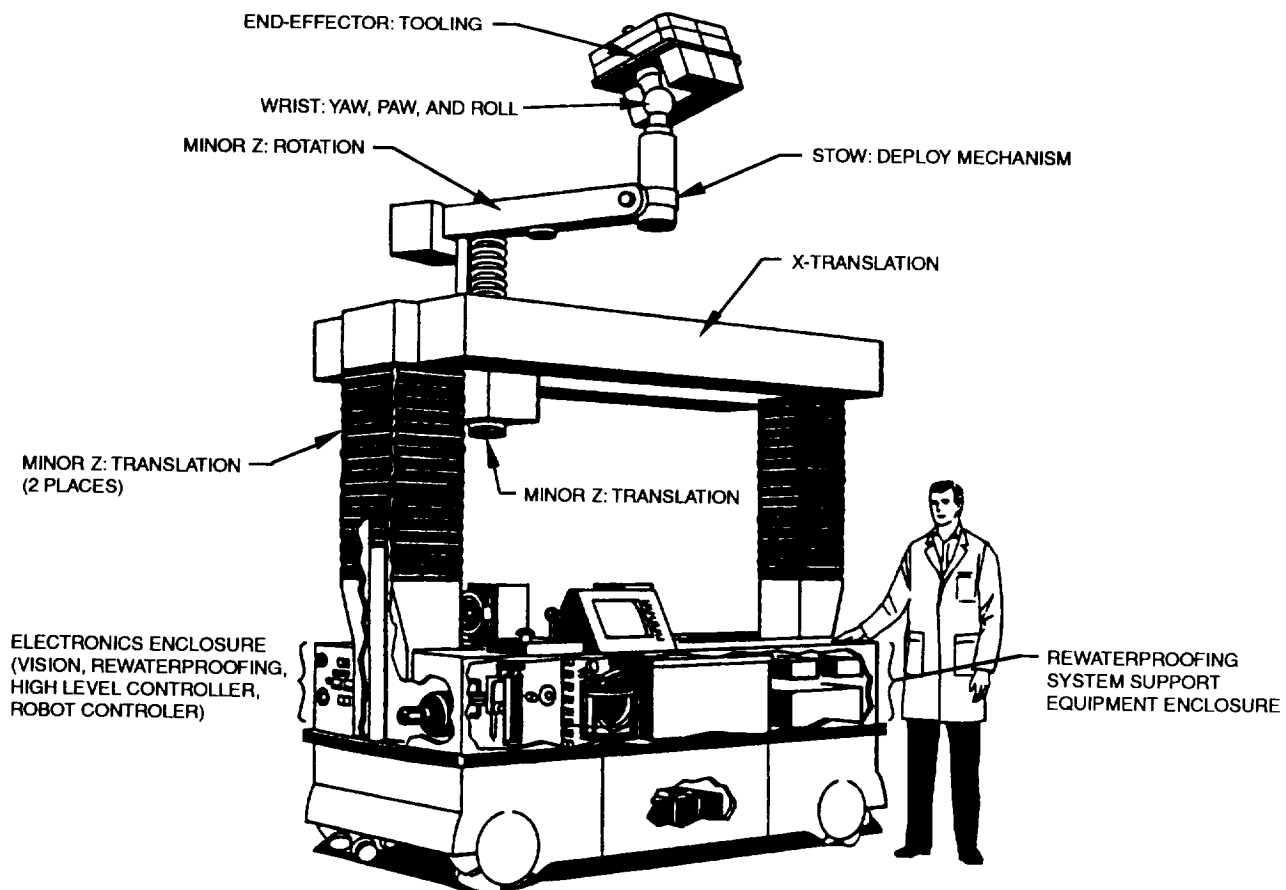
Additionally, an effort is underway to develop a prototype system for three-dimensional characterization of tile defects. This effort is focusing on developing a compact system that can be integrated into the existing robot end-effector. Various demonstrations will be made throughout the year to show feasibility and sensor performance.

Key accomplishments and milestones:

- 1991: Project initiated and subsystem designs are 30 to 40 percent completed.
- 1992: Technology demonstration of mobile base, vision, and rewaterproofing subsystems.
- 1993: Subsystem design completed and system integration initiated.
- 1994: Prototype mobile robot delivered to KSC. Continue system development, integration, and testing.
- 1995: Complete system development, integration, and testing. System demonstration of the fully functioning prototype.
- 1996: Certification and implementation of the system into Orbiter processing.

Contacts: C.L. Parrish, DM-ASD, (407) 867-4181, and T.A. Graham, DM-ASD, (407) 867-3797

Participating Organizations: I-NET Space Services (R.R. Bennett); Carnegie Mellon University (K. Dowling); NASA Langley Research Center (E. Cooper); SRI International (C. Cowan); and Rockwell International Corporation (D. Manouchehri)



KSC Tile Robot Configuration

Serpentine Truss Manipulator (STM)

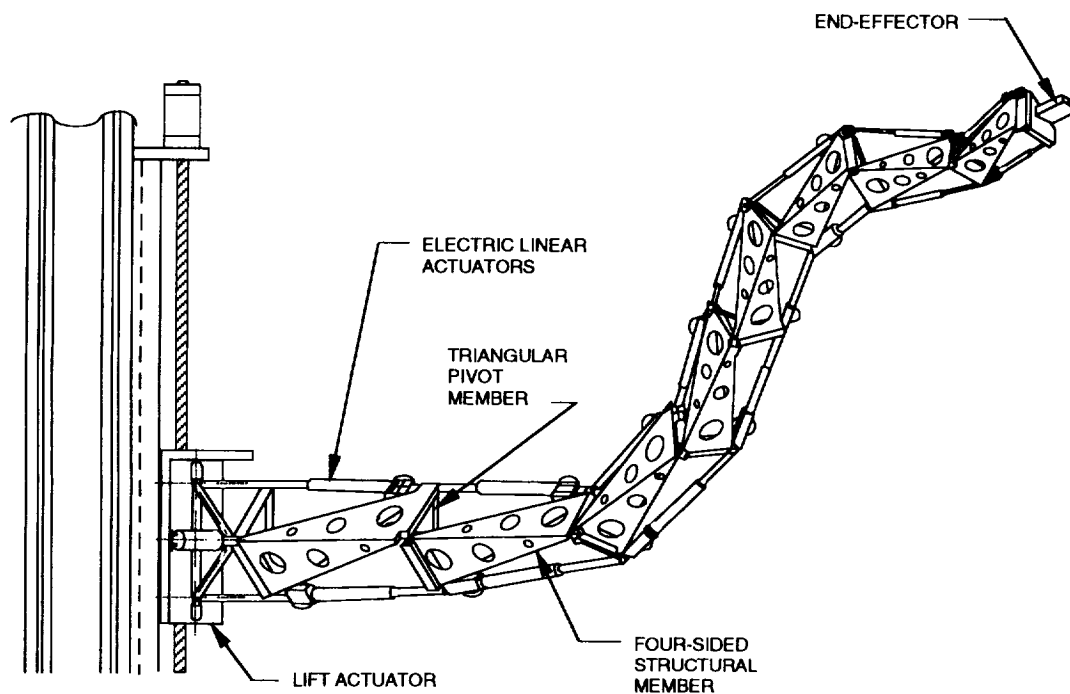
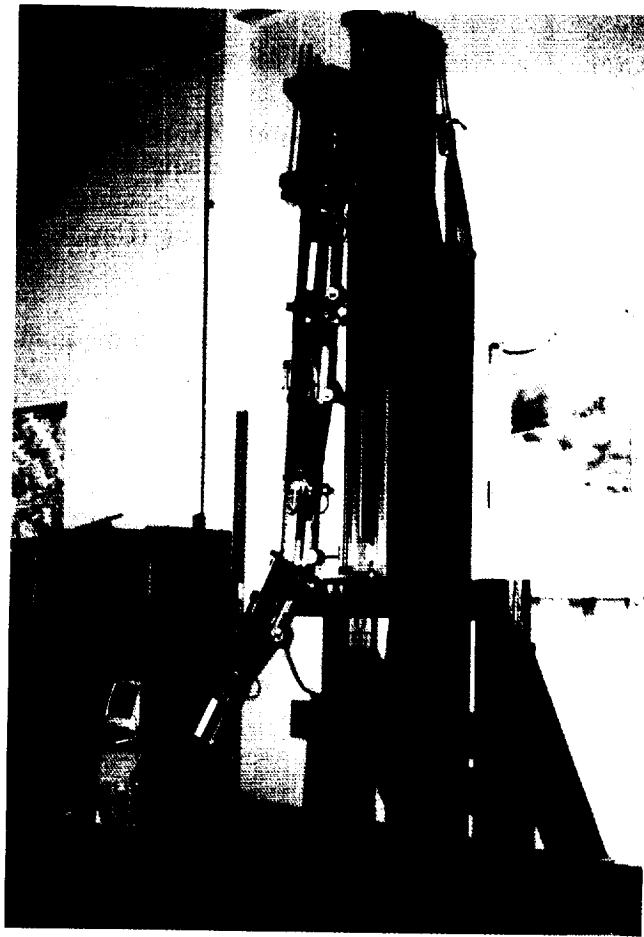
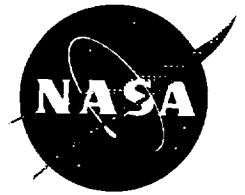
This redundant degree-of-freedom (DOF) robot manipulator was developed by the KSC Advanced Systems Development Laboratory (ASDL) to serve as a proof-of-concept development test bed for advanced robot technologies. The STM was designed and built by Foster Miller, Inc., of Waltham, Massachusetts, under a Small Business Innovation Research (SBIR) project. The system is presently in the ASDL where it is being used as a prototype to test and develop many of the enabling technologies for the Payload Inspection and Processing System (PIPS).

The STM is a variable geometry truss structure that has 18-DOF movement, enabling it to perform highly articulated movements. Variable geometry truss manipulators are composed of truss segments with one or more of the sides capable of being extended or retracted. This gives them the ability to change their geometry as shown in the figure "Serpentine Truss Manipulator." The advantages of these structures are their relatively simple mechanisms, light weight, and high rigidity. The STM uses electric linear ball screw actuators to move its 18 joints. It is controlled by a high-speed 486 processor-based PC running custom software written in C++.

The main thrust of the ongoing development work with the STM is to prove concepts and technologies to be used in the operational PIPS. As part of this, algorithms are being developed and tested for "serpentine motion" control of multi-DOF robot manipulators. Conventional robot arms move by "sweeping out volumes" in space, but serpentine motion is similar to pushing a wire down a curved pipe (i.e., the manipulator links follow the tip trajectory). This control is required in the PIPS, which will thread into highly constrained areas around sensitive flight hardware. The STM is being used in a realistic payload mockup to test obstacle avoidance and sensing using a unique SensorSkin. The SensorSkin is a redundant safety system that will be used in the PIPS project to prevent collisions between the robot and flight hardware. The SensorSkin is a flexible material embedded with infrared proximity sensors and acoustic proximity sensors and is wrapped around the serpentine manipulators. Along with the sensors, the SensorSkin has miniaturized control electronics that interpret the signals from the sensors and communicate with the robot controller. This technology is being developed by Merritt Systems, Inc., of Merritt Island, Florida, under an SBIR contract. Other technologies being developed using the STM include distributed control system architecture and fiber-optic communication/video data links. These activities will continue through 1997 until the completion of the PIPS project.

Contacts: A. Biamonte, CS-PPD-21, (407) 867-4789; G. Tamasi, DM-ASD, (407) 867-4156; and C.L. Parrish, DM-ASD, (407) 867-4181

Participating Organization: Foster Miller, Inc.



Serpentine Truss Manipulator

Advanced Payload Transfer Measurement System

The objective of this project is to develop a simple, low-cost, robust, centrally operated, and portable system to automatically measure the three-dimensional offsets between the payload trunnions and their supports during payload transfer operations in the Vertical Processing Facility (VPF), the Orbiter Processing Facility (OPF), the Operations and Checkout Building (O&C), the Space Station Processing Facility (SSPF), and the Payload Changeout Room (PCR).

Trunnions are standard structural components used to secure payloads to the Space Shuttle cargo bay and to the payload processing facilities. When loading multiple payloads, six to twelve of them must be moved in a coordinated manner to carefully secure the payloads on their support latch or hooks. Currently, a technician is required at each trunnion location to measure the three-dimensional offsets using tethered rulers. The move conductor uses an intercom system to find out the offsets from each trunnion technician and maneuvers the payloads by sending verbal commands to a crane operator. The system under development will consist of a network of coordinate measurement transducers attached to each trunnion. Data from each transducer will be displayed to the move conductor on a computer screen. Studies of 1993 cost data for operations at the OPF and PCR indicate a potential savings of \$110K per year. Similar numbers are expected for operations in the O&C, SSPF, and VPF. Time savings of 1 to 4 hours per payload transfer operation are anticipated. This system will increase measurement accuracy and reliability, reduce error opportunities, increase payloads and technician safety, and provide an avenue for payload transfer automation in the PCR and VPF. Future expansion capabilities include very fast calculations of the next move command and closed-loop control for greater time savings. The coordinate measurement transducer also has commercial potential in the areas of crane operations, construction, assembly, manufacturing, automotive, and aerospace.

Key milestones:

- 1995: Prototype coordinate measurement transducer hardware and software to display offset information for six trunnions. System verification and demonstration in the Automated Systems Laboratory.
- 1996 to 1997: Procurement, fabrication, testing, and installation of units in the OPF, PCR, VPF, and O&C.

Contacts: E. Lòpez del Castillo and C.L. Parrish, DM-ASD, (407) 867-4181

Participating Organizations: NASA (P.M. Mortillaro, TV-MSD-5; S.J. Payne, TP-PED-3; and M.D. Bruder, CG-LSO-2); I-NET Space Services (R.R. Bennett); Rockwell Space Systems Division (D. Tamir); McDonnell Douglas Space and Defense Systems (J.A. McGinley); and Lockheed Space Operations Company (N.P. Reutt)



Payload Lift From Cargo Bay, OPF High Bay 1

Advanced Life Support Automated Remote Manipulator (ALSARM)

The objective of the ALSARM project is to develop a prototype system to take environmental measurements inside the Biomass Production Chamber (BPC) breadboard project (also known as the Controlled Ecological Life Support System or CELSS) at KSC. This project is being performed in conjunction with the University of Central Florida (UCF). A two-semester design course at UCF resulted in several concepts for the ALSARM. KSC and UCF decided on a final concept that would meet all the system and BPC requirements. The project is approximately 30 percent complete and will conclude in mid-1995 with a demonstration of the prototype ALSARM in the BPC.

The BPC consists of two separate levels that are used to grow crops in an almost totally enclosed environment. The BPC will help NASA understand how to grow crops in space for lunar or Martian bases. During the course of study, technicians have to enter the chamber to measure environmental parameters, such as air temperature, leaf temperature, infrared temperature, relative humidity, air velocity, and light levels. Entry of personnel into the BPC disturbs the environment in several ways. The opening of the chamber door accounts for about half of the chamber's daily leak rate. The technicians contaminate the environment by their respiration, which expels carbon dioxide and organic products. The mere presence of the technicians can modify the airflow patterns in the BPC. The environmental measurements, which take about an hour, are performed serially. Also, it is difficult for people to take measurements at exactly the same points from one type of measurement to another or from one test to another. The ALSARM will be an automated method of taking these measurements, which will eliminate personnel entry, reduce the chamber leak rate, and allow for more consistent measurements.

The ALSARM will integrate state-of-the-art systems in control, mobility, manipulation, information management, and sensor technologies to perform the BPC environmental measurements. Eventually the system may be expanded to include an end-effector (or tool) on the manipulator to take plant samples and eventually perform other functions such as planting and harvesting.

Key design features of the ALSARM include: (1) control via a tether cable, (2) a 3-degree-of-freedom robot manipulator, (3) a multiple sensor array on the end-effector, and (4) interfaces to existing NASA databases.

The accomplishments for 1994 include the conceptual phase final report, initial system requirements, and fabrication of an engineering test model. Demonstrations were made to develop the method of extending the manipulator arm and geometry fit check of the arm in the BPC.

Completing the ALSARM design will be the major effort for the remainder of 1994. The design and system fabrication are expected to be complete in 1995. Integration and testing of the ALSARM subsystems (vertical arm for Z translation, rotation fixture for rotation about the vertical arm, manipulator and end-effector, electrical system, sensor array, and data acquisition system) is expected to be complete by mid-1995.

Key accomplishments and milestones:

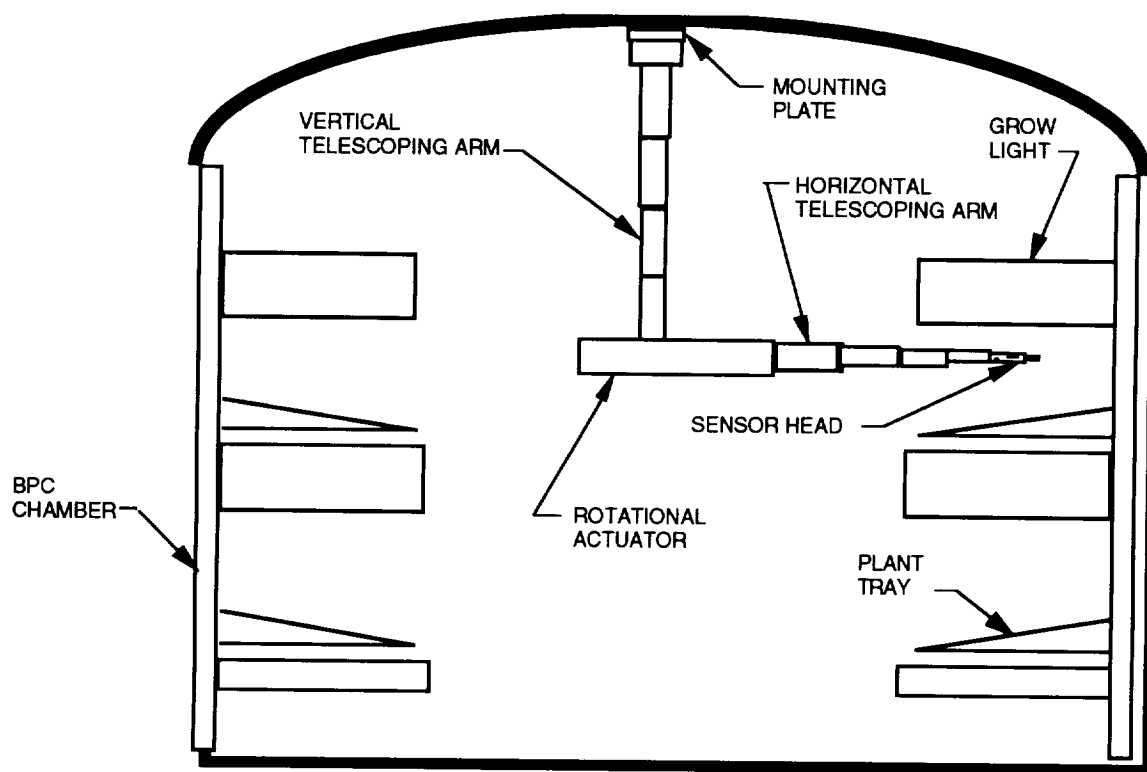
- August 1993: Project initiated and concept designs evaluated.
- June 1994: Final report and design concept completed.
- October 1994: System requirements review completed.
- October 1994: 30 percent design review.



- November 1994: 60 percent design review.
- November 1994: 90 percent design review.
- December 1994: Final review.
- March 1995: Fabrication of ALSARM complete.
- April 1995: Integration and testing of ALSARM complete.

Contacts: M.D. Hogue, DM-ASD, (407) 867-7777; C.L. Parrish, DM-ASD, (407) 867-4181; and Dr. J.C. Sager, MD-RES, (407) 853-5142

Participating Organization: University of Central Florida (Dr. R. Johnson, Dr. Z. Qu, and N. Baker)



ALSARM Concept Design

Launch Complex 39 Payload Changeout Room HEPA Filter Inspection System (HFIS)

An application for a robotic system has been developed at KSC as an effective means to aid NASA engineers to further improve ground-based, launch-related processing of the Space Shuttle and its associated facilities. The unique, custom-designed robotic system was developed by engineers in the Advanced System Development Laboratory (ASDL) to automate a dangerous and critical time-consuming task of High-Efficiency Particulate Accumulator (HEPA) filter inspection in the launch pad Payload Changeout Room (PCR).

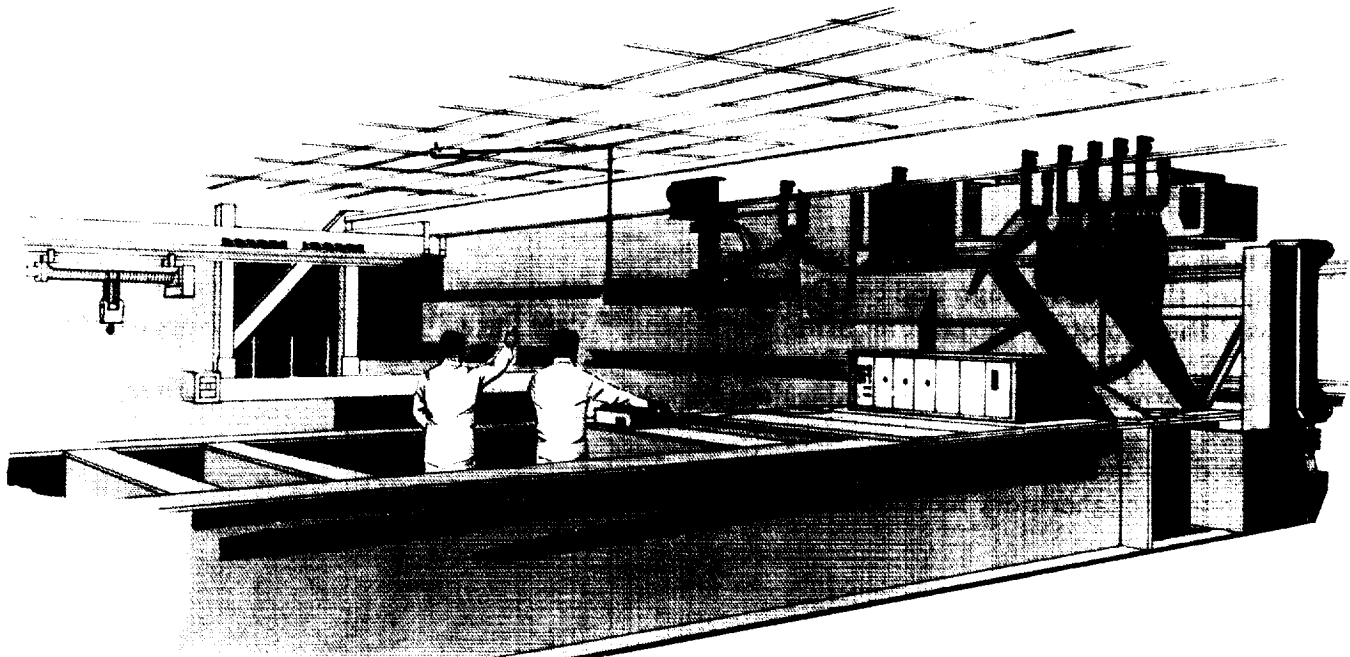
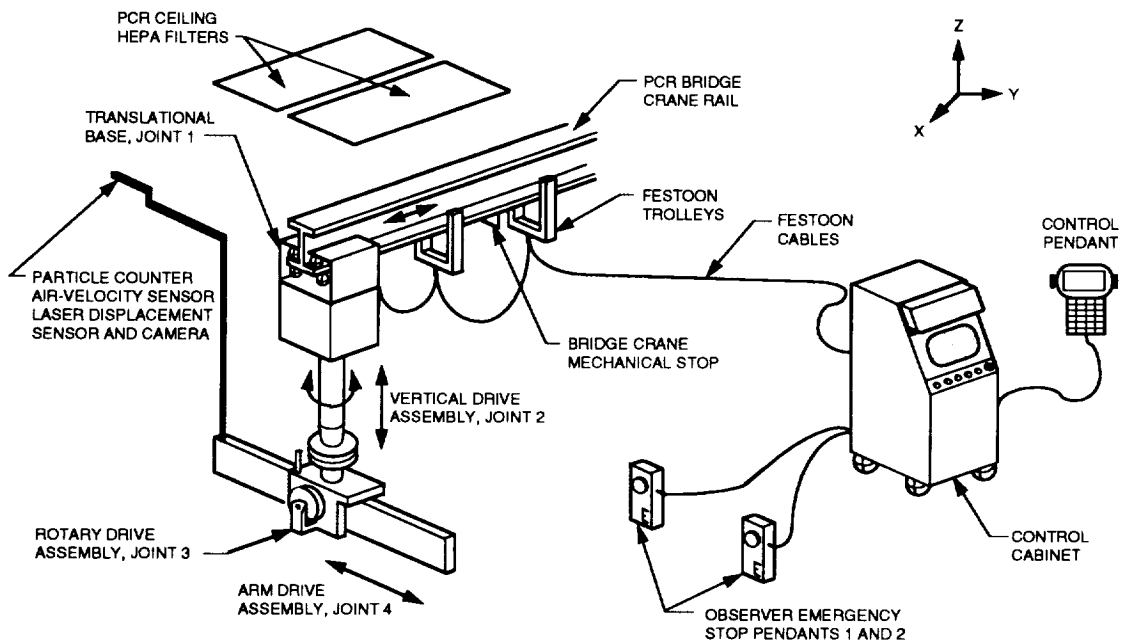
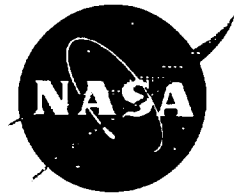
Previously, filter inspection was performed manually and took about 120 man-hours to complete. This inspection task required technicians to utilize ladders and special access platforms deployed on top of a six-story, movable structure inside the PCR. This massive structure, known as the Payload Ground-Handling Mechanism (PGHM), is used to move satellites and other payloads in and out of the Shuttle orbiter's cargo bay.

The HFIS is a 4-degree-of-freedom (DOF) robot that utilizes the existing 5-ton bridge crane rails in the PCR ceiling to implement its fourth degree of freedom (gross positioning). The HFIS mechanism has an integrated end-effector consisting of the following: a particulate counter, an air velocity sensor, a laser distance sensor, and a CCD video camera. The HFIS is controlled through a user-friendly graphical interface via a supervisory computer system consisting of an input/output processor, motion controller, and host computer. System users can manually or automatically perform HEPA filter inspection with the device, with real-time filter test status provided to the operator by the graphical user interface and test data recorded on a tape drive for later analysis and reporting.

In June 1994, the HFIS project team successfully completed integration and programming of the HFIS system in the PCR at Launch Complex 39, Pad A. Pad A acceptance testing was also performed, which completed 50 percent of the system turnover to operations. Work is continuing to complete the system integration and programming at Pad B. The HFIS team resumed work at Pad B after the November launch of STS-66. It is anticipated that full system turnover will take place before December 1994, after which the system will be used regularly by Shuttle Operations to perform filter inspections.

Contacts: G. Tamasi, DM-ASD, (407) 867-4156; C.L. Parrish, DM-ASD, (407) 867-4181; and M.R. Murazzi, TV-MSD-21, (407) 861-3629

Participating Organization: I-NET Space Services (J.E. Spencer and C.J. Looney)



HEPA Filter Inspection System (HFIS)

Payload Inspection and Processing System (PIPS)

A project is being initiated to design and develop a robotic system for Space Shuttle payload bay and payload processing operations in the launch pad Payload Changeout Room (PCR). A study and conceptual design was completed to identify and evaluate processing tasks that would benefit from the use of a robotic system to perform inspections and light manipulation in difficult access areas around payloads. Due to space and reach constraints, payload access in these facilities can be difficult. Some processing tasks are as simple as inspecting the proper mating of connectors or the removal of camera lens caps, but the tasks still require expensive custom-designed access platforms and pik-boards to reach the area. The PIPS will be designed to reach these areas and perform these processing tasks, thereby eliminating considerable expense and hazards associated with the present operations. Operations at the PCR were the prime focus of the effort; however, other facilities such as the Orbiter Processing Facility (OPF) were also considered.

The PIPS will be flexible enough to "thread" into the highly constrained payload areas and perform visual inspections, payload closeout photography, contingency inspections and verifications, spot cleaning, foreign object debris removal, cover installation and removal, and line connections. The conceptual system is made up of a unique long-reach (3 meters) serpentine manipulator covered by an obstacle detection proximity SensorSkin, inspection cameras and a vision system, end-effector grippers and cleaning tools, a telescoping boom to which the serpentine arm is attached, a 2-degree-of-freedom pointing base, a mobile control station, path-planning software, and a graphical world model user interface. The main features include portable components that break down into two-person-carrying subassemblies, a wheeled control station cabinet, a facility interface to existing platform mounting locations, off-line programming, teleoperated control, and redundant safety systems. The design emphasizes a quick setup, minimal facility modification, use in multiple facilities, clean room operation, and ease of use by trained technicians. This concept will be analyzed in detail in the design process and may be subject to changes as the design develops.

Key accomplishments:

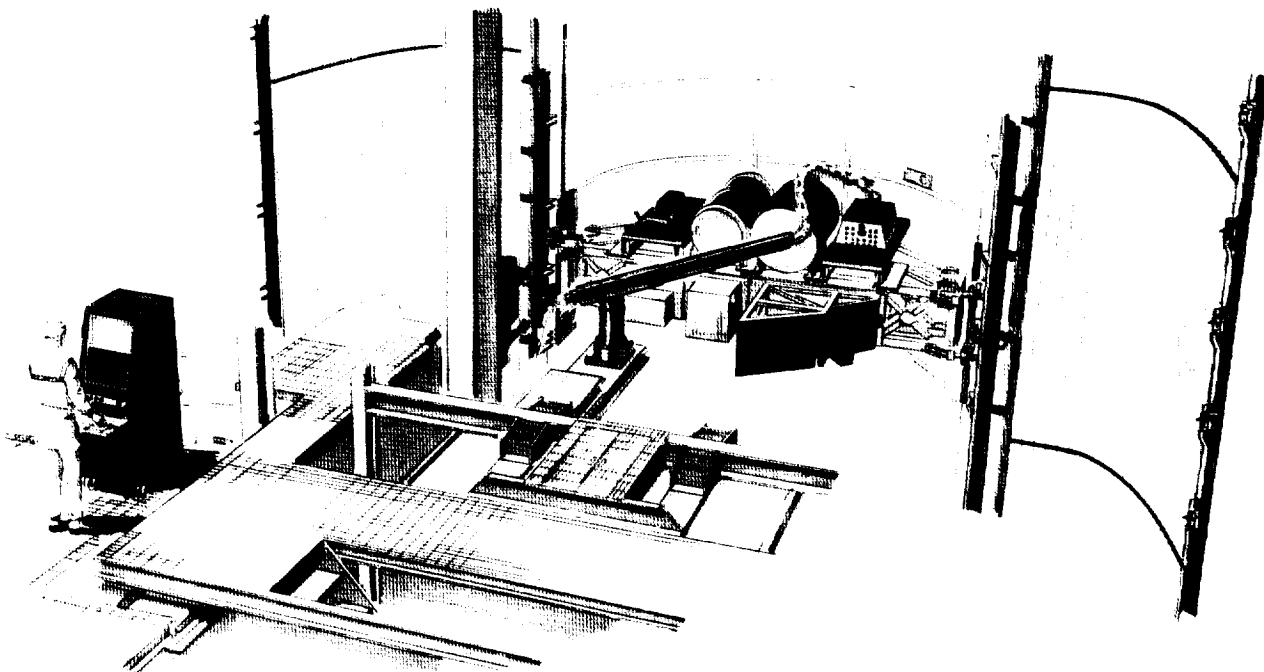
- Performed a system study and need analysis.
- Completed the initial design and computer graphic model of the conceptual robot design.
- Received the prototype serpentine arm (Serpentine Truss) built by Foster Miller, Inc., through a Phase II Small Business Innovation Research (SBIR) project.
- Received the prototype SensorSkin developed by Merritt Systems, Inc., through a Phase II SBIR project.
- Completed the design requirements document.
- Built a realistic laboratory mockup of the PCR environment for test purposes.

Key milestones:

- PIPS conceptual design.
- Expand prototype serpentine arm to 18 degrees of freedom.
- Demonstrate the prototype serpentine manipulator arm and SensorSkin in a laboratory mockup.

Contacts: A. Biamonte, CS-PPD-21, (407) 867-4789, and G. Tamasi and C.L. Parrish, DM-ASD, (407) 867-4156

Participating Organization: McDonnell Douglas Space Systems (M.E. Sklar and B. Richardson)



Payload Inspection and Processing System



Payload Inspection and Processing Robot

Laser Coordinate Measurement System

The main objective of this project is to calibrate automated mechanisms and positioning control systems developed or integrated under the supervision of the KSC Advanced Systems Development Laboratory (ASDL). In addition, candidate applications are being sought in the Shuttle, Payload, and Base Operations Contract that can benefit from using the three-dimensional Laser Coordinate Measurement System (3-D CMS). Some applications under study include:

1. Holddown post bearing alignment on the Mobile Launcher Platform
2. Payload Changeout Room (PCR) Clean Access Platform (CAP) motion profile measurement
3. PCR Payload Support Beam (PSB) straightness measurements
4. Facilities, ground support equipment, and flight hardware contour measurements
5. Precise installation of flight components and experiments
6. Positioning and alignment of precision instruments
7. Solid rocket booster stacking operations

The CMS-3000 laser coordinate measurement machine is a commercially available servo-controlled laser tracker interferometer tool manufactured by the Special Matrix Corporation and acquired by the ASDL in September 1993. The unit has a Class II (0.5 milliwatt) helium-neon (HeNe) laser. The laser beam in the tracker is reflected back from a 1.5-inch-diameter retroreflector target and measures the position in space of the center of the target relative to a coordinate system fixed to the instrument. It can track a target moving at 18 feet per second and accelerating at 2 g's at a minimum distance of 3 feet from the laser source. The radial measurement range is 100 feet. The instrument can collect up to 800 data points per second. It is easy to define user coordinate systems and to perform coordinate transformations. The data can be imported into a spread sheet or a database to perform formatting, editing, analysis, and reporting functions.

Key accomplishments to date include a total savings of an estimated \$60,000 on the following jobs:

- 1994:
 - PCR CAP motion profile measurement and coordinate transformation.
 - PCR PSB straightness measurements.
 - Automated Tile Processing System (ATPS) base and manipulator repeatability and accuracy measurements.
 - Locating the vertex of the tiles in the mockup for the ATPS.
 - HEPA Filter Inspection System repeatability and accuracy test.
 - Installation of the rack support beams for a mockup of the Space Station Modules.
 - Verification of retroreflective binary encoded target location for the navigation systems of the ATPS and the Mobile Automatic Cleaning System.



Key milestones:

- 1995:
 - Use the CMS-3000 laser to align bearings on the holddown posts and compare results with current methods.
 - Test the built-in level sensor.
 - ATPS mockup survey and robot calibration.

Contacts: E. Lopez del Castillo and C.L. Parrish, DM-ASD, (407) 867-4181

Participating Organizations: NASA (A.C. Littlefield, L.E. Moctezuma, and D.E. Dehart), Lockheed Space Operations (T.K. Brooks), and Special Matrix Corporation (J. Shaw)



Industrial Engineering (IE) at the John F. Kennedy Space Center (KSC) is a key to further improving the efficiency of ground processing operations. The processing facilities at KSC are factory environments, and factories are the traditional domains of industrial engineers. KSC IE research and technology development efforts are usually different from research efforts in other engineering disciplines because the products of IE research efforts are frequently new or improved methodologies or processes. Advanced IE technologies typically focus on applying basic IE principles to new domains (such as orbiter processing where shop floor tasks are relatively infrequent, are dynamic, and have long durations) or on cost-effectively applying new technologies (such as advanced software or robotics) to improve overall process performance. Current areas of IE technology development include human factors/methods engineering, work measurement, process modeling and statistical analysis, and benchmarking. The near-term focus of IE is within Shuttle ground processing. The long-term focus will be on expansion to other KSC flight hardware processing facilities, support shops, and laboratories and on developing other applicable areas of IE.

Industrial Engineering

Industrial Engineering Productivity Prototype

From an industrial engineering (IE) perspective, the facilities used for Shuttle processing at KSC are NASA's premier factories. The products of these factories are some of the most spectacular products in the world — safe and successful Shuttle launches. The factory is also the traditional domain of industrial engineers. Most IE functions, tools, and techniques evolved from the need to improve shop floor productivity to remain competitive in the marketplace. At the beginning of this project, no formal IE office existed in NASA/KSC Shuttle processing operations. Increasing competition for federal funds, decreasing Shuttle processing budgets, and a stable flight rate have encouraged the development of an IE organization to streamline the activities on and supporting the KSC shop floors.

The KSC factories are similar to depot-level maintenance environments, but they are different in many ways from high-volume production and assembly-line factories. For example, the tasks executed during flight hardware processing are relatively infrequent and dynamic, with long cycle times. However, the primary processes necessary to prepare a Shuttle for launch (such as providing parts, planning the work flow, and executing tasks) are common to most factory environments. Therefore, it was believed that the same benefits (e.g., improved productivity) could be derived from the application of IE principles if they were adapted for the KSC Shuttle processing environment. After demonstrating the applicability and benefits of IE during several successful projects in Thermal Protection System (TPS) processing, an applied research effort was initiated in 1991 to develop a NASA IE capability. This effort is called the "productivity prototype."

The first step in the productivity prototype effort was to select the traditional IE functions with the highest payback potential for KSC. After studying shop floor operations and productivity levels, the following four functions evolved:

1. Methods engineering: designing tasks to minimize task time, worker effort, and overall cost while maximizing safety and quality.
2. Work measurement: estimating how long a task *should take*, comparing the estimate to how long it *does take*, and using the comparison data for process and organizational improvement.
3. Benchmarking: quantitatively comparing process performance with "world-class" leaders to set process improvement goals and strategies to meet these goals.
4. Process modeling and statistical analysis: supporting decisionmaking by modeling and analyzing complex processes with IE tools, such as discrete event simulation.

The functional relationship of these four IE functions is illustrated in the figure "Industrial Engineering Functional Relationship." Elements of each function overlap and support the other functions. The IE functions are further described in several additional articles in this R&T report. All four functions did not previously exist in NASA Shuttle Operations. They have been taken from concept, through design and initial development, and will soon be implemented, as shown in the figure "Industrial Engineering Function Life Cycle."

The processing of the Main Propulsion System (MPS) in the Orbiter Processing Facility (OPF) was studied in detail during the first phase of the prototype. During the second phase, tasks were sampled from all orbiter systems in the OPF. Some IE functions (facilities management, planning/scheduling, and inventory control) already exist in Shuttle management. By integrating the new and existing IE functions,



the goal is to make KSC, with NASA's premier factories, a recognized "center of excellence" in industrial engineering.

Key accomplishments:

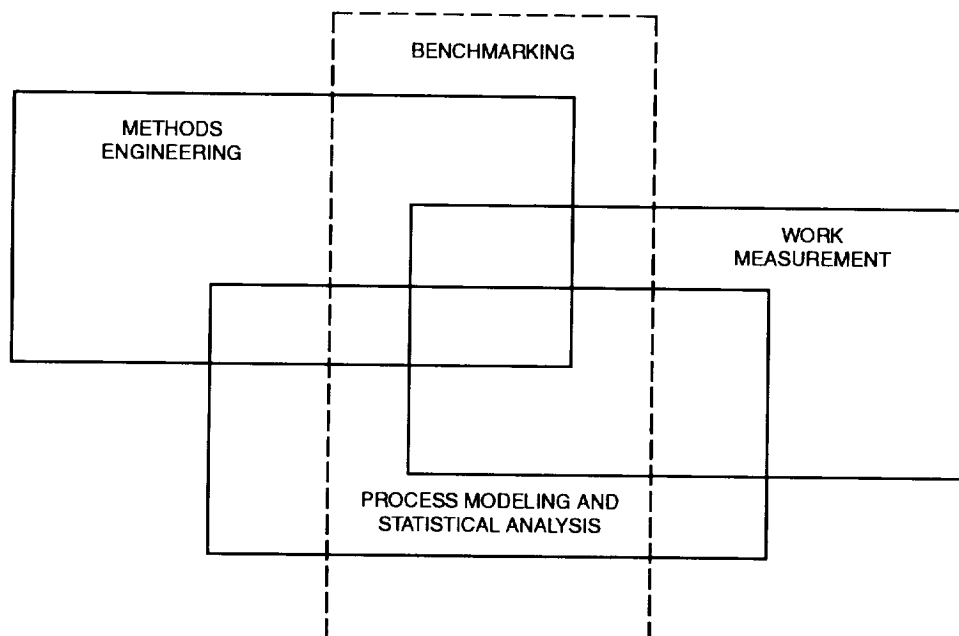
- 1991: Initial productivity measurements and review of existing/previous KSC IE efforts.
- 1992: TPS IE projects completed. NASA Shuttle Operations Industrial Engineering Office established.
- 1993: Phase 1 Productivity Prototype (MPS study) completed.
- 1994: Phase 2 Productivity Prototype (OPF study) completed.

Key milestone:

- 1995: Formal implementation of four new IE functions in Shuttle processing operations.

Contacts: T.S. Barth, A. Mitskevich, and J.A. Leotta, TP-PED-1, (407) 861-5433

Participating Organization: University of Central Florida (R. Safford, W. Swart, J. Pet-Edwards, K. Stanney, S. Murray, and M. Archer)



Industrial Engineering Functional Relationship

| CONCEPT | DESIGN | DEVELOPMENT | IMPLEMENTATION | OPERATIONS AND MAINTENANCE |
|--|--------|-------------|------------------------|---|
| IE Office With the University of Central Florida | | | IE Office Plus Support | IE Office With the Shuttle Management and Operations Directorate and Shuttle Processing Contract Groups |

Industrial Engineering Function Life Cycle

Adaptation of Methods Analysis Techniques for Shuttle Processing

A primary concern in industrial engineering is performing necessary tasks while minimizing resource utilization. Methods analysis includes several human factors engineering tools that enable determination of the optimal work methods for a required task. An analysis of existing work methods examines: (1) how methods use limited resources (e.g., time, energy, material, and money), (2) how methods physically and psychologically affect workers, and (3) the quality of the results. Improved methods design can increase productivity (e.g., reduce time, energy, material, and money expended), reduce worker effort (e.g., reduce the potential for strain or injury), and improve the quality of the output (e.g., reduce the potential for errors). An effort to develop, modify, and customize methods analysis techniques for improving productivity in Shuttle processing was initiated in 1992. The top figure illustrates the components of a methods analysis in the Orbiter Processing Facility (OPF).

During Phase 1 of this project, a subset of processing tasks was studied in detail. The subset of tasks was the main propulsion system (MPS) "normal flow" tasks in the OPF. These tasks did not include unplanned work, such as interim problem reports. The MPS was used as a representative OPF system for demonstration purposes. The Phase 1 effort included an ergonomic tool review, direct observations of tasks, and an examination of the work instructions. The operation process chart for MPS processing in the OPF is shown in the bottom figure.

Several areas for work methods improvements were identified during Phase 1, and appropriate methods analysis techniques were customized for the Shuttle processing environment. Examples of methods improvements included paperwork consistency, optimizing work content and work flow, and sequence-level resource listings. The Phase 2 effort is currently assessing the potential benefits of methods analysis across all orbiter systems processed in the OPF and is developing cost-effective approaches for applying work methods analysis techniques. The major purpose of the effort is to validate and extend the results from the MPS study to other orbiter systems and unplanned work in the OPF.

Key accomplishments:

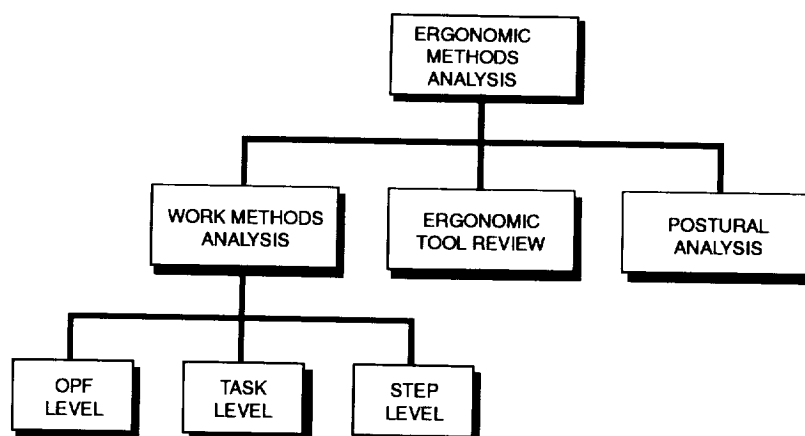
- 1992: Completion of MPS operation process chart.
- 1993: MPS work instruction and ergonomic tool review.

Key milestones:

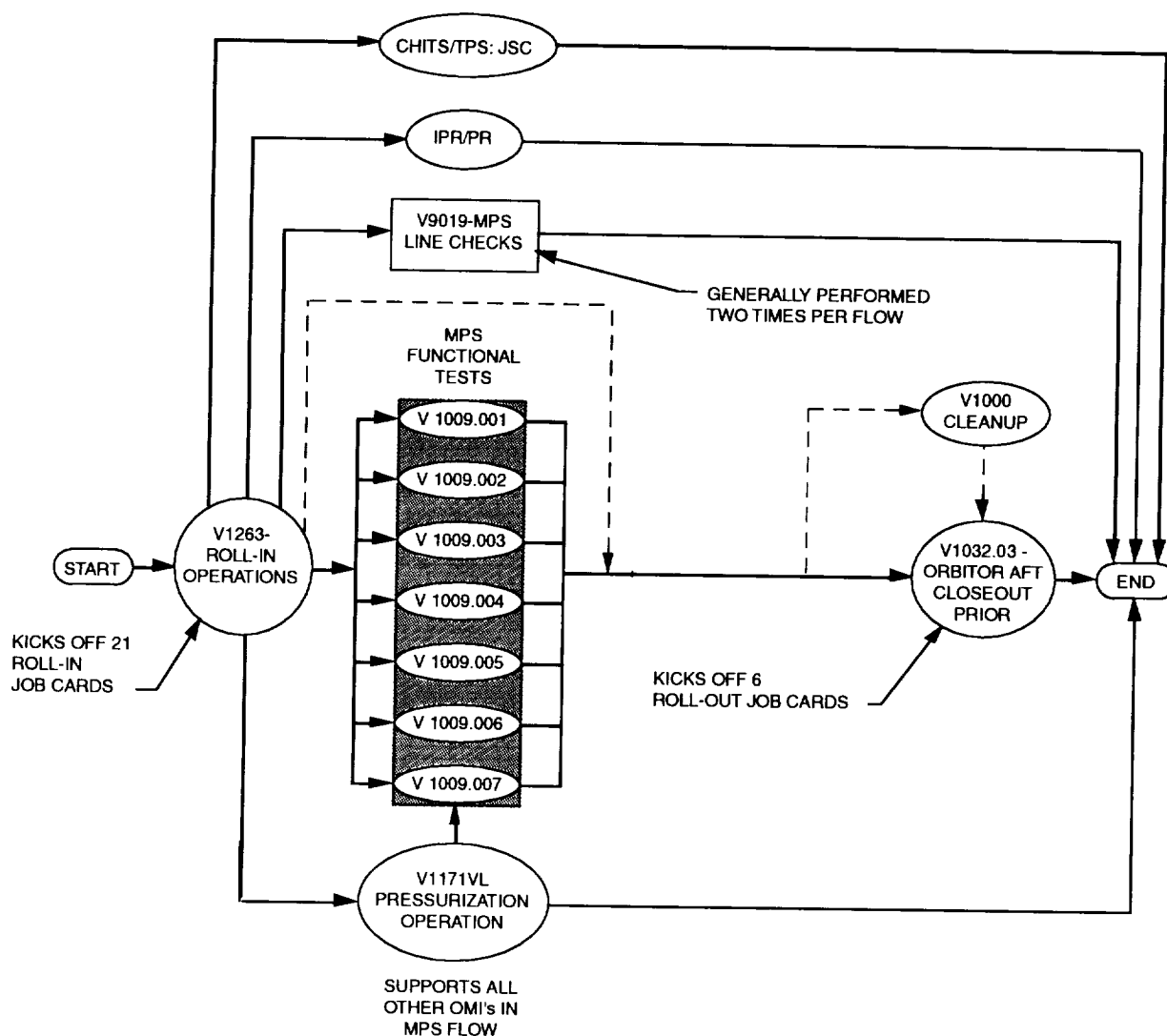
- 1994: Completion of OPF planned work methods analysis across orbiter systems. Recommendations for improving OPF work instructions.
- 1995: Development of a methodology for selecting cost-effective methods analysis techniques. Evaluation of the impact of unplanned work in the OPF.

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Participating Organization: University of Central Florida (J. Pet-Edwards and K. Stanney)



Methods Analysis Components in the OPF



Operation Process for Main Propulsion System Processing in the OPF

Adaptation of Work Measurement for the Shuttle Processing Environment

Shifting Government priorities, an increasing public concern with Government spending, and the resulting reductions in funding have encouraged NASA to begin investigating the use of traditional industrial engineering techniques to increase the efficiency and effectiveness of Space Shuttle ground processing. One key industrial engineering area being addressed at KSC to enable gains in efficiency and effectiveness is work measurement, which has been successfully applied in manufacturing industries on short-duration, highly repetitive tasks to measure and improve performance. The processing at KSC of a Shuttle for flight consists of many long-duration, low-repetition tasks in an environment with many safety and quality concerns. Currently, limited data has been collected on how long a task takes, but virtually no data is available on how long a job should take. The selection of the appropriate work measurement technique to develop these "should take" estimates or task standards is the first step in implementing a comprehensive work measurement program. This is the initial focus for the adaptation of work measurement to KSC's Shuttle processing environment.

In order to address this issue, a feasibility study was conducted to better understand the processing environment and how work measurement techniques could be effectively applied to develop task standards. All work measurement techniques were initially evaluated for feasibility in Shuttle processing. Those found to be feasible were studied further by first concentrating on one orbiter system, the main propulsion system (MPS). The analysis was then expanded to include 80 percent of orbiter processing work in the Orbiter Processing Facility, based on the results from the MPS study. Job clusters were developed based on task characteristics with the hypothesis being that similar types of work require the same work measurement techniques.

Times were collected on tasks that fell within each job cluster by adapting the feasible work measurement techniques. Allowances for personal, fatigue, and delay conditions and job-specific conditions were applied to these times, which were then adjusted to reflect the slower pace required in an environment with high quality and safety standards and limited learning curve benefits. In order to select the "best" technique for each job cluster, several criteria (see the figure "Selection Criteria for Work Measurement Technique") were developed and weighted for importance. The weighted criteria were applied by job cluster for each work measurement technique, with the technique receiving the highest overall value being selected for application to tasks within that job cluster. Future plans include the development of a KSC standard for work measurement and the initial implementation of a reporting and analysis system to ensure the use of work measurement data for process improvement.

Key accomplishments:

- 1992: Determination that work measurement is feasible for orbiter processing; determination of which work measurement techniques can be used for orbiter processing.
- 1993: Development of a systematic approach to select and apply work measurement techniques for particular types of jobs (see the figure "Systematic Approach for Standards Development").
- 1994: Classification of orbiter processing tasks into job clusters; determination of which work measurement techniques should be used for orbiter processing.

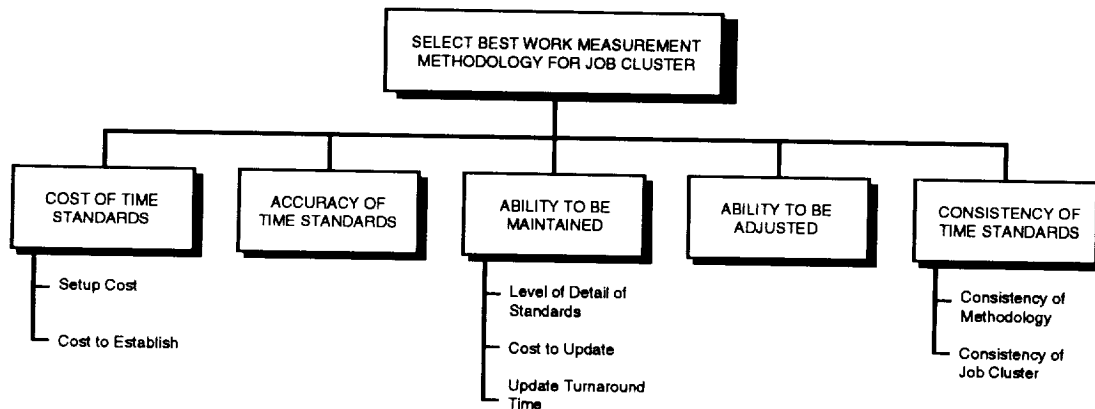
Key milestones:

- 1995: Expansion of the study into other Shuttle areas. Development of a system for measuring actuals against standards to identify areas for improvement. Initial implementation of a work measurement program in Shuttle processing operations.

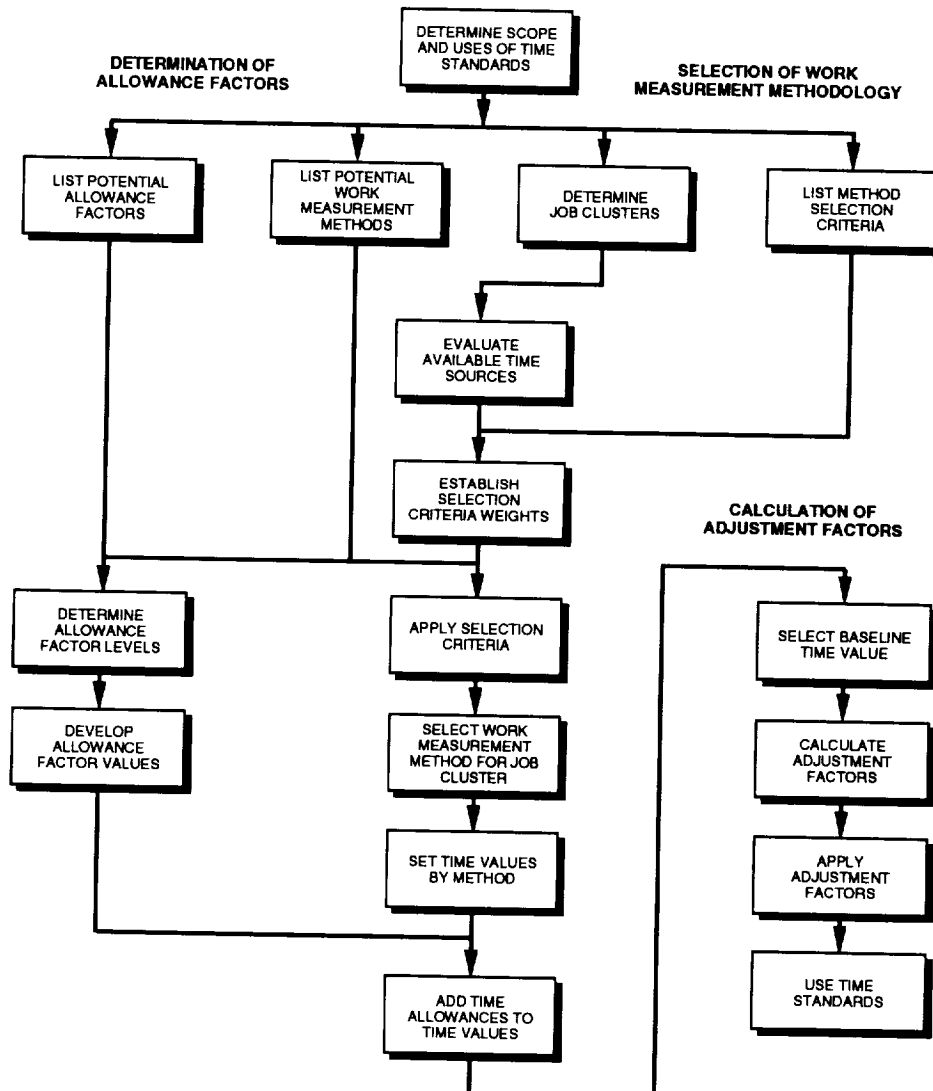


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Participating Organization: University of Central Florida (S. Murray and B. Safford)



Selection Criteria for Work Measurement Technique



Systematic Approach for Standards Development

Team Effectiveness in Shuttle Processing

One of the four major industrial engineering functions being developed to support Shuttle processing is methods engineering, in which tasks are designed to minimize cost and worker effort while maximizing safety and quality. Methods engineering in the KSC "factories" includes consideration of several unique human factors issues. At KSC, nearly all processing tasks are accomplished by teams rather than by individual workers. Therefore, team effectiveness should be optimized as part of the methods engineering of shop floor tasks.

The shop floor teams in this study typically consist of technicians, quality personnel, system engineers, and special support crews. Trained observers from NASA Ames Research Center, the Center for Creative Leadership, and the U.S. Air Force Academy collected data by shadowing shop floor personnel for 5 weeks during the summer of 1994. The direct observation data was supplemented with data obtained from team member questionnaires.

The project has two major goals: (1) to perform basic research to understand organizationally embedded teams and (2) to perform applied research for answering specific KSC management questions. The basic research focused on testing and refining the team effectiveness leadership model (see the figure). The applied research consisted of items such as:

1. Determining the most efficient and effective level of teamwork for a specific category of processing tasks. Teamwork is a continuum of work efforts (see the figure). Team work is not simply off or on — it has many levels, and the best level for a specific task depends on several characteristics.
2. Determining when "in-tact" teams are more appropriate than "formed" teams. This work supported the KSC study for systems-oriented teaming. At KSC, many teams are formed only for single tasks rather than being dedicated to routine tasks or engineering systems.
3. Analyzing and enhancing the task team leader training program. Effective leadership is the most important component of effective teams. KSC currently has task team leaders that will benefit from additional leadership training.
4. Studying the use/misuse of continuous improvement and tiger teams. For solving some problems, tiger teams can be more effective than continuous improvement teams. Management needs to know in advance what type of team to charter for a specific problem.

Key accomplishments:

- 1991: Human Factors Engineering memorandum of understanding between KSC and Ames Research Center signed.
- 1992: Team dynamics research in payload processing.
- 1993: Basic team effectiveness research in several Shuttle processing facilities.
- 1994: Applied team effectiveness research in Orbiter Processing Facilities.

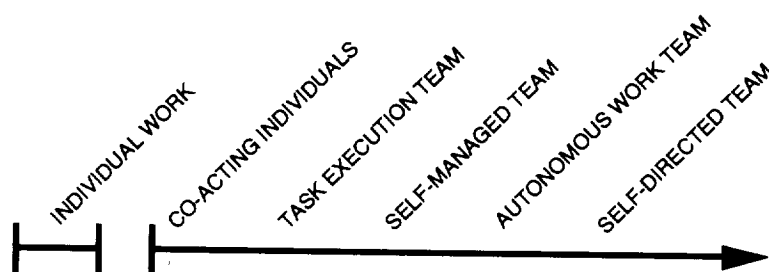
Key milestone:

- 1995: Final report and recommendations for Shuttle processing teamwork enhancements.

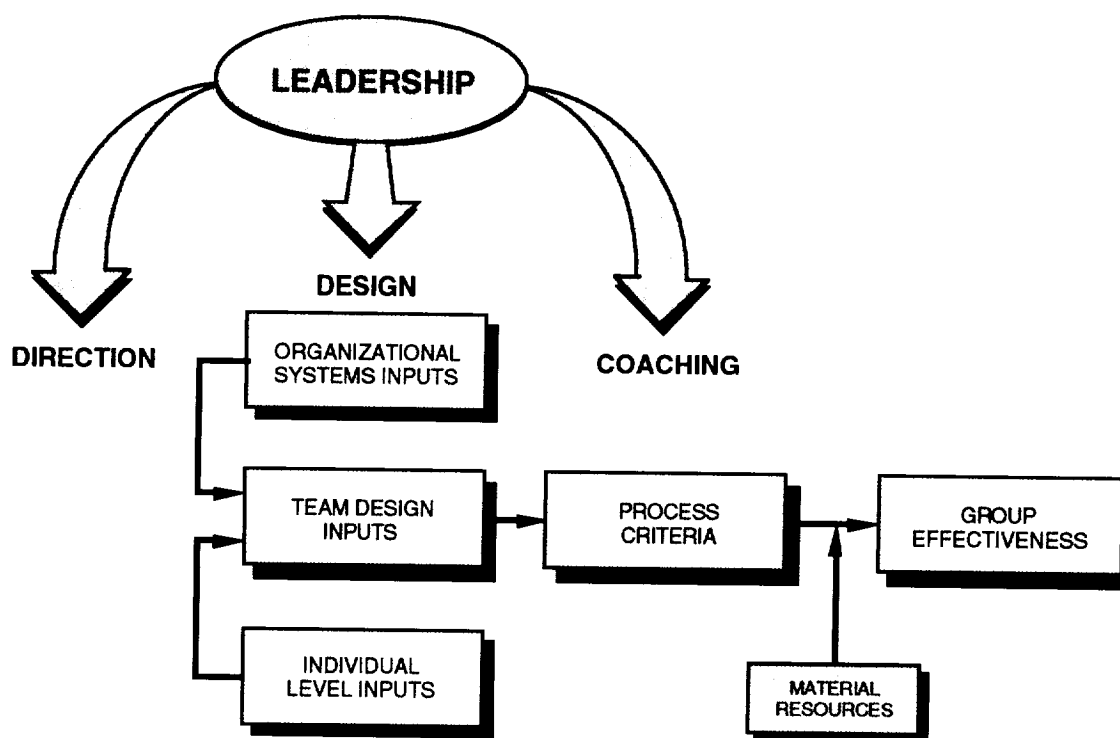


Contact: T.S. Barth, TP-PED-1, (407) 861-5433

Participating Organizations: Ames Research Center (B. Kanki), Center for Creative Leadership (R. Ginnett), and U.S. Air Force Academy (J. Austin)



A Continuum of Work Efforts



Team Effectiveness Leadership Model®

Benchmarking of Shuttle Processing Operations

The continuous improvement process (CIP) implemented at KSC provides a strong foundation for adapting and using benchmarking tools to support process improvement activities. Benchmarking permits groups of process owners and stakeholders to evaluate their individual functions while comparing those functions to other groups who perform similar processes. A two-phase research project is scheduled for completion in early 1995. A type of benchmarking called interfacility comparison has been studied in detail. Interfacility comparison is centered around a structured process identification and measurement activity to support the required comparative analyses. An example of an interfacility benchmarking report is shown in the graph, which gives the percentage of the schedule milestones met. Process comparisons developed during this research activity will provide useful information for future improvement activities within Shuttle processing.

The initial activities centered around the development of a systematic procedure for identifying and analyzing processes for benchmarking comparison. A detailed literature review was performed to define the state of the art in benchmarking applications to facilitate the development and implementation of comparison activities at KSC. Participating facilities from the Shuttle processing organization were selected, and stakeholders within the facilities were identified. Additionally, high-level measures necessary to compare organizational-level performance across facilities were evaluated, and candidate measurements were identified. Participation in facilities benchmarking discussions via the NASA-wide Video Teleconference System (VITS) has also been a part of the Phase 2 research activity. An industrial engineering survey of aerospace and depot-level repair facilities has been initiated to permit comparison of industrial engineering functions across a broad spectrum of organizations. This activity will enable future industry and Government benchmarking partnerships.

The process-level measurement system developed during Phase 1 is being implemented across the selected facilities: Hypergolic Maintenance Facility (HMF); Rotation, Process, and Surge Facility (RPSF); and three Orbiter Processing Facility (OPF) high bays. The Interfacility Productivity and Performance Measurement System (IPPMS) provides a structured process identification and measurement system for use in any organization. The bilevel approach (process level and organizational level) to process analysis is being developed to better understand the internal processes of Shuttle processing before attempting to benchmark with other organizations.

Key accomplishments:

- 1993: Development of the systematic process disaggregation procedure (PDP) illustrated in the figure "Disaggregation Pyramid." Selection of welding and leak-check operations for process-level benchmarking between KSC facilities.
- 1994: Initiation of data collection activities in the HMF, RPSF, and OPF bays. Completion of independent assessment of the benchmarking activities of the NASA-wide facilities maintenance benchmarking group.

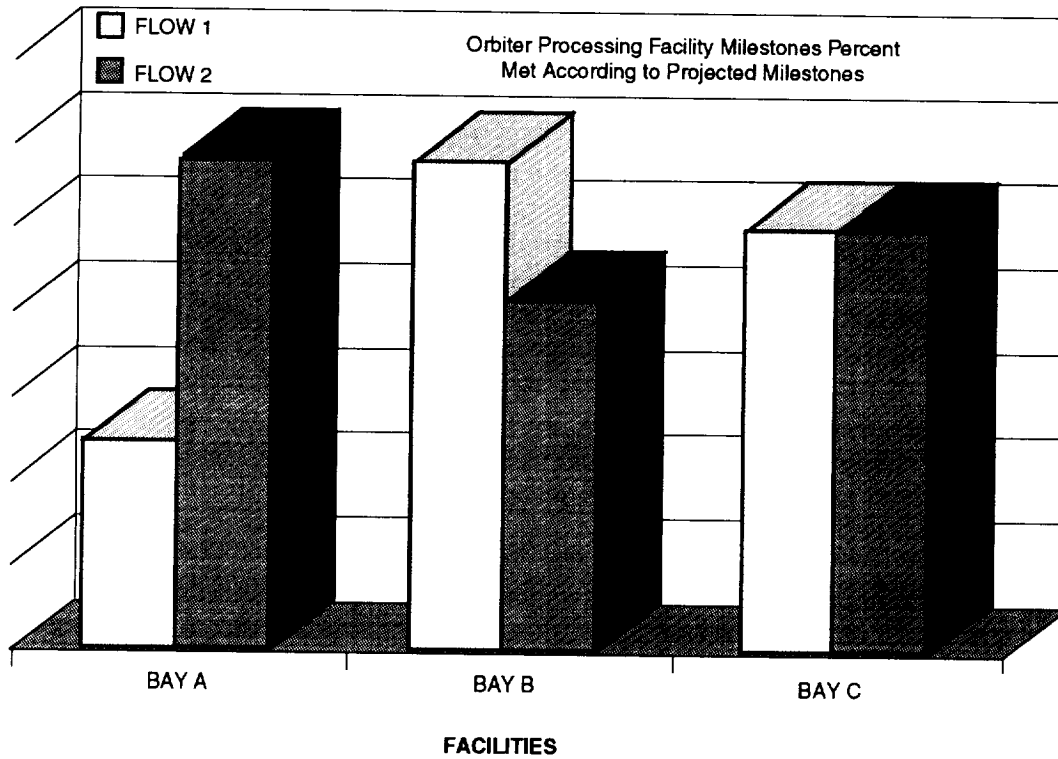
Key milestones:

- 1995: Completion of industrial engineering functional benchmarking study. Initial process-level interfacility comparisons complete for welding and leak-check operations. Completion of a list of candidate measures for all primary organizational-level processes. Initiation of NASA-wide planning/scheduling common interest group leading to external benchmarking of scheduling processes.

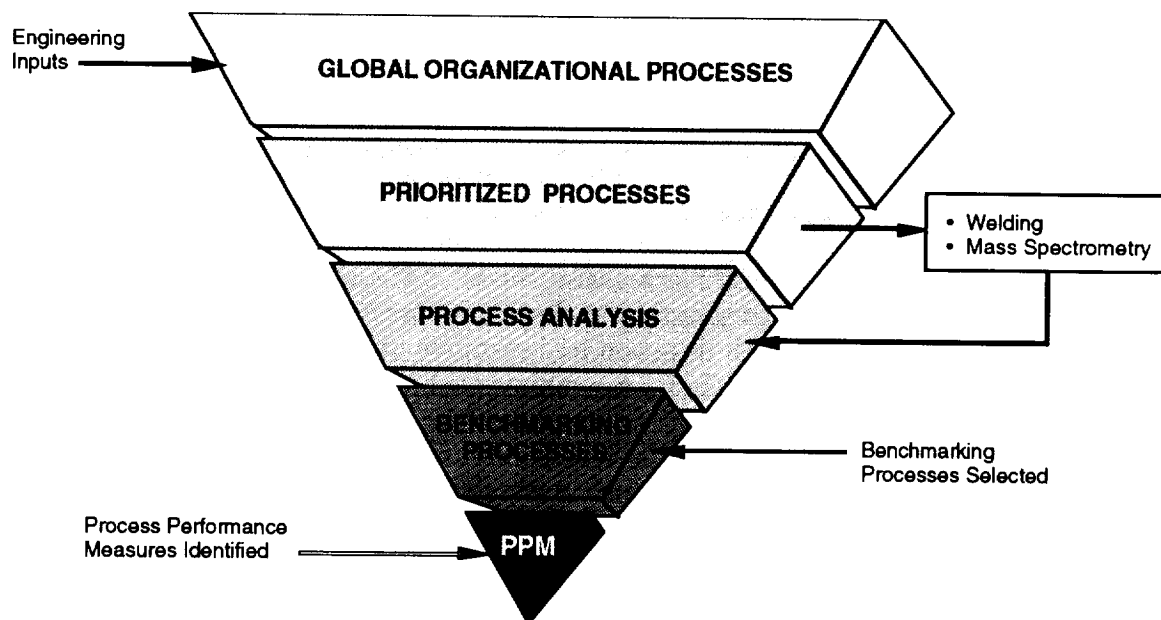


Contact: T.S. Barth, TP-PED-1, (407) 861-5433

Participating Organization: University of Central Florida (R. Safford and A. Jackson)



Example of Interfacility Benchmarking Report



Disaggregation Pyramid

Discrete Event Simulation as a Decision-Support Tool for Space Shuttle Ground Processing

The major processes used in Space Shuttle ground processing are all dynamic and have a relatively large degree of uncertainty. In order to make better decisions by recognizing and accounting for this uncertainty, these processes must be modeled and quantified. Discrete event simulation enhances decision-support systems by representing parameters with variability as probability distributions. This allows the impact of changing these parameters with respect to critical outputs to be quantified in a computer model before the changes are made to the real process or system.

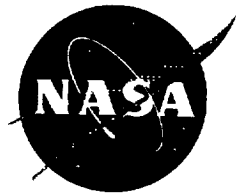
One of the most dynamic KSC processes is ground processing flow planning and scheduling. The traditional application of discrete event simulation is in mass production manufacturing environments. In these models, entities are processed through a simulated system, and statistics on variables (such as throughput or queue length) are collected. In the dynamic nature of KSC's flow planning and scheduling process, the variables of interest and the model structure are less traditional. Consequently, before applying this technology, a feasibility study was performed. Two primary levels of flow planning were identified as areas of consideration: the Orbiter Processing Facility (OPF) task level and the interfacility level. Prototype models at each level were built using a commercial off-the-shelf discrete event simulation tool.

To evaluate flow planning at the OPF task level, a generic, reusable simulation model was developed that simulates a network of tasks. As each simulated task begins, an attempt to obtain the resources required to complete the task is made; however, if resources cannot be obtained, the task waits. This generic model was first applied to a prototype system, the Main Propulsion System (MPS) processing activities, where the model was also used as a quantification tool to support work measurement and methods engineering efforts. A working group of NASA and Shuttle Processing Contract MPS engineers was formed to obtain detailed input data, which was used to enhance the model to include configuration requirements and interactions outside the MPS. Examples of output information available from this model are:

1. Amount of time each task waited for resources and configuration
2. Resource utilizations
3. Total project duration and variance

A preliminary model of a full-scale OPF processing model at the task level was also developed using the generic network model based on information in the Computer Aided Planning and Scheduling System (CAPSS). This model provides both duration and resource information to assess how the existing information in the CAPSS can be used to build a complete OPF simulation model.

To evaluate flow planning at the interfacility level, a launch processing simulation model was developed. This model evaluates the number of launches per year based on expected processing durations and the number of OPF shifts available. Variation from the planned launch date is also evaluated in the near term since fixed milestone dates are available for input. This model will be used to evaluate over-time required to meet planned launch dates in the near term and the expected launch rate per year in the long term.



Key accomplishments:

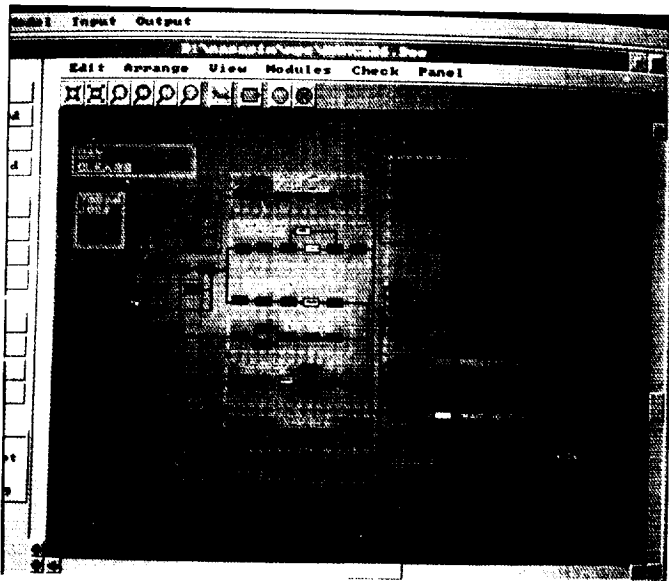
- 1993: Development of a reusable modeling methodology to simulate task-based activities.
- 1994: Development of a detailed simulation model of MPS processing activities, a preliminary simulation model of OPF processing activities, and a model to represent launch-processing activities at KSC. Determination of data available documenting OPF task precedence relationships, resource requirements, and configuration requirements.

Key milestones:

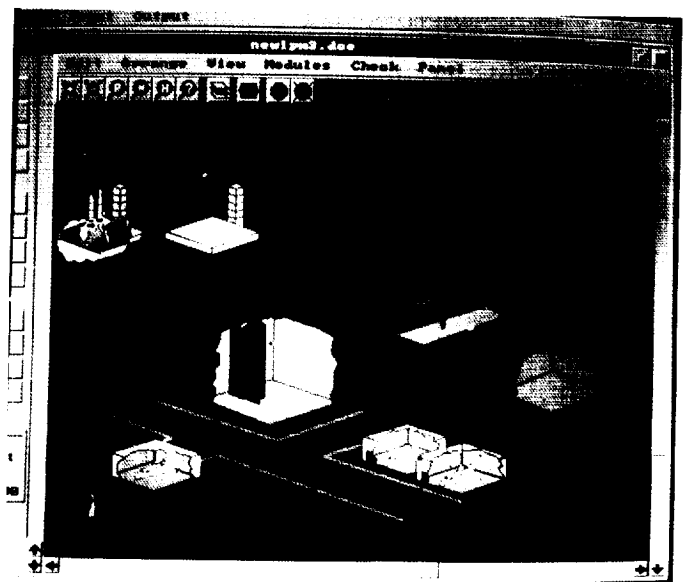
- Establish the Launch Processing Model as an on-line tool to support manifest planning. Expand the OPF model using the generic network methodology based on user requirements. Expand the application of Discrete Event Simulation to other KSC processes, such as parts and materials provisioning and work execution.

Contact: J. Leotta, TP-PED-1, (407) 861-5428

Participating Organization: University of Central Florida (M. Archer and B. Safford)



MPS Simulation Model During Run Mode



Launch Processing Simulation Model During Run Mode

Schedule and Cost-Risk Analysis Model (SCRAM)

Innovative methods and software for schedule and cost-risk analysis of Shuttle ground processing are being developed under a Small Business Innovation Research (SBIR) contract. A major goal of the risk analysis is to identify the kinds of delays that are having the most impact on KSC ground processing schedule length and cost.

The project is a 2-year Phase II SBIR effort. The main focus of the contract is to design and implement the SCRAM system. The SCRAM system has three components: a risk analysis module, a schedule module, and a system executive. Existing commercial software was used wherever possible to minimize the technical risk of the project. The risk analysis module is based on Lumina Decision System's Demos product, and the schedule module is based on the Schedule Publisher from Advanced Management Solutions. SCRAM is a significant improvement to the state of the art in schedule and cost-risk analysis because it allows realistic models of schedule variables (e.g., task lengths) to be built and analyzed. Previous project risk analysis tools provided constrained and limited modeling capabilities. While SCRAM was designed with Shuttle ground processing in mind, it will be applicable to any complex schedule and cost-risk analysis and has substantial commercial potential.

To date, the project focused on developing a Macintosh-based SCRAM system that builds on the prototyping effort of the Phase I SBIR contract. This system improves on the first system by allowing seamless integration between the three modules of the system and facilities to allow the analysis of very large schedules. Future plans include five research tasks to enhance SCRAM capabilities, the design and implementation of a PC-based version of SCRAM, and the application of SCRAM to Shuttle ground processing scheduling, as well as to a second, unrelated scheduling task.

Key accomplishments:

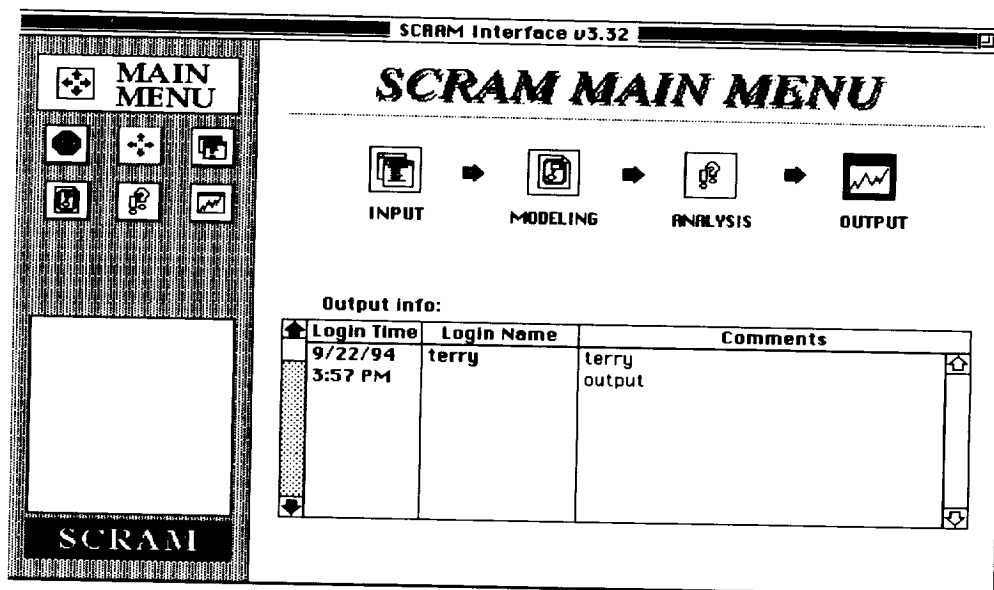
- 1992: Award of the Phase I SBIR contract.
- 1993: Completion of the Phase I feasibility study and SCRAM prototype.
- 1994: Research, design, and implementation of a resource-constrained criticality algorithm. Completion of a Macintosh-based SCRAM system.

Key milestones:

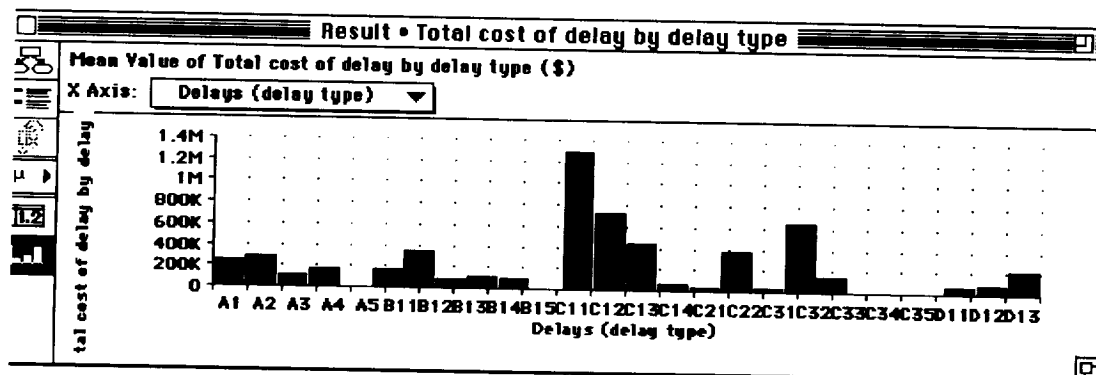
- 1995: Complete the PC-based SCRAM system. Apply the SCRAM system to analyzing the schedule and cost risk in the Orbiter Processing Facility ground processing.
- 1996: Apply the SCRAM system to analyzing the schedule and cost risk of another KSC project.

Contact: T.S. Barth, TP-PED-1, (407) 861-5433

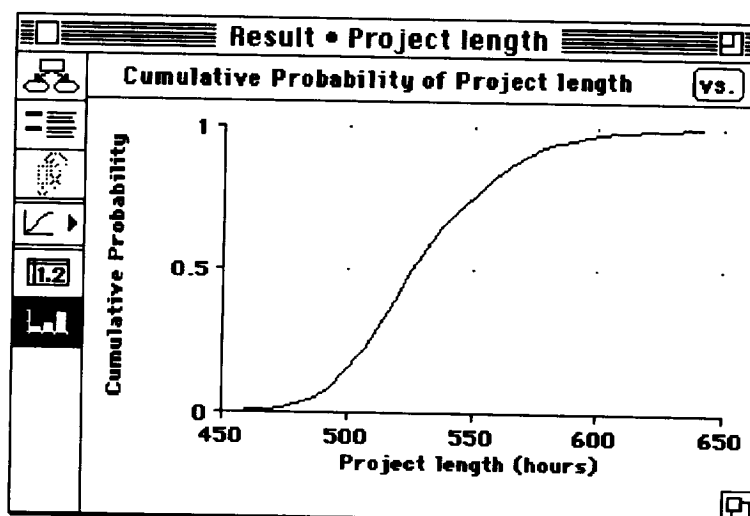
Participating Organization: Lumina Decision Systems (R. Fung and M. Henrion)



Introductory Screen to the Macintosh SCRAM System



SCRAM Delay Importance Analysis for the Phase I Case Study



Probability Distribution on Schedule Length for the Phase I Case Study

Variable-Form Data Collection and Analysis

Space Shuttle ground processing at KSC involves the execution of thousands of written work instructions. Variable data elements are frequently collected during the execution of work steps. Examples of variable data elements include torque readings, leak rates from mass spectrometer probe operations, and ambient temperature readings. The variable data elements are used primarily for real-time control and to ensure functional conformance to specifications. Knowledge of conformity is useful information; however, additional information and analysis are needed to quantify the potential for process improvement and/or re-engineering. The statistical process control procedures necessary for continuous improvement require that actual variable data values of the process performance measures (PPM's) be available. Ready availability of PPM's will enable the development of control charts for delineation of common and special causes, process capability analysis, continuous process performance monitoring, and other useful statistical process control tools. The overall objective of this research activity is to specify procedures and to develop the necessary tools for variable-form data activities of ground processing test and checkout tasks.

The project is made up of three integrated components (see the figure "Project Components and Integration").

1. Opportunity assessment: In this component, test and checkout tasks will be surveyed with the objective of identifying tasks with high potential for process improvement and re-engineering. Consideration will be given to technician and engineer input, availability of statistical data, and payback potential.
2. Application of statistical process control (SPC) techniques on selected processes: As a proof of concept, a number of processes are selected for re-engineering. Data are collected and SPC techniques are applied in the justification of process improvement measures. This pilot study will enable the identification and design of optimum SPC methods for KSC tasks.
3. Development of a computer-based intelligent system for data analysis and capability measurement: To identify processes for improvement and to quantify the potential for re-engineering, application of SPC techniques on variable data is necessary. This component of the project will provide the system design and the necessary software to ensure the availability of variable data in a format amenable for process capability measurement and its viability for improvement. The system is expected to have an intelligent component to enable analysis in selecting the proper SPC technique and to assist in the interpretation of the analysis results.

Key accomplishments:

- 1994: Variable-form data analysis on two Thermal Protection System (TPS) processes completed, resulting in a direct savings of approximately 200 man-hours per flow (see the figure "Capability Analysis for TPS-P217"). Survey initiated to measure overall opportunity for process improvement by variable-form data analysis.

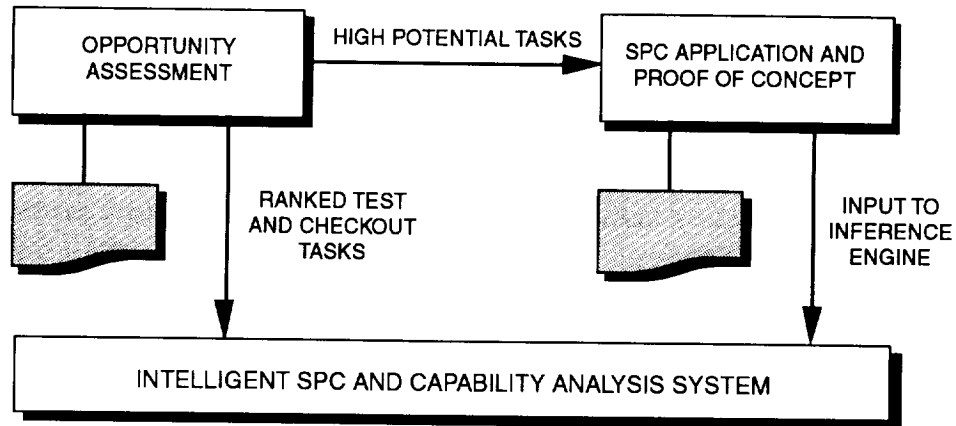
Key milestones:

- 1995: Completion of the opportunity assessment and additional variable-form data test cases.
- 1996: Completion of the prototype Intelligent Capability Analysis System.

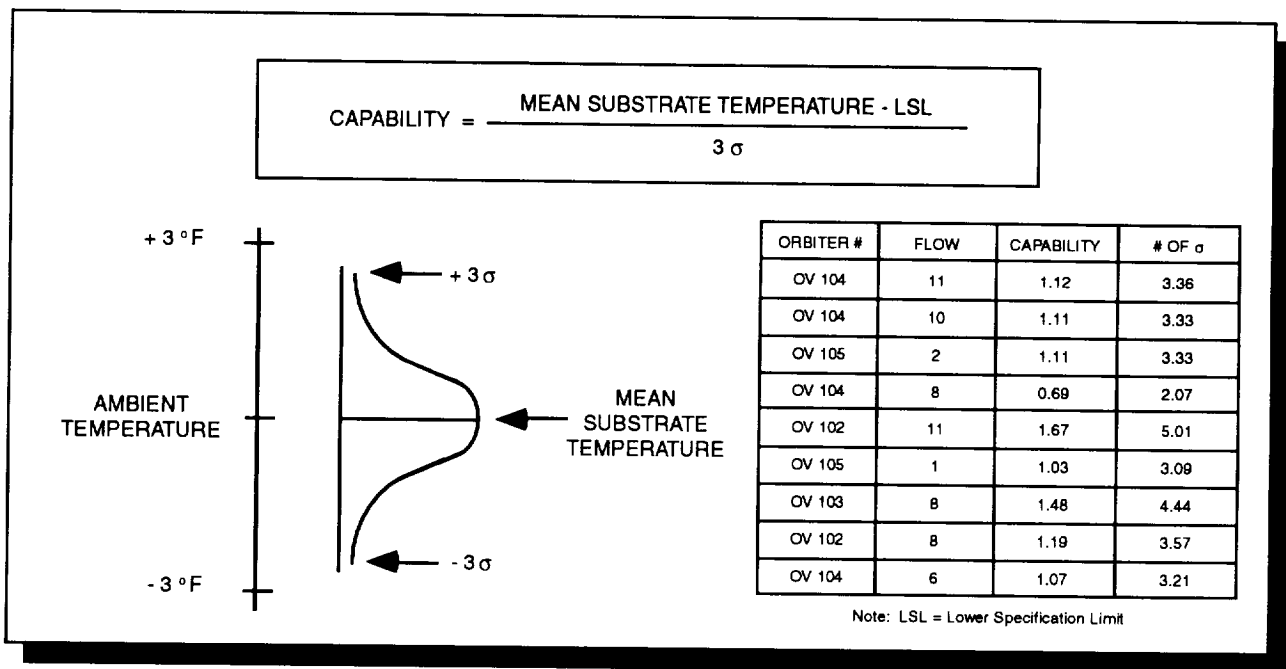


Contact: T.S. Barth, TP-PED-1, (407) 861-5433

Participating Organization: University of Central Florida (Y. Hosni, R. Safford, D. Osborne, and T. Sotomayor)



Project Components and Integration



Capability Analysis for TPS-P217

Shop Floor Modeling, Analysis, and Reporting Tool (SMART)

The KSC Shop Floor Control/Data Collection (SFC/DC) system stores data regarding the start and end times of a work authorization document (WAD), start and end times of stoppages experienced by a WAD, and a delay category for the stoppage. This data is being collected to enable building models of the Shuttle test and checkout process and its associated support activities. The primary goal is to develop methods and tools (1) to effectively access and manipulate the SFC/DC data, (2) to analyze the SFC/DC data for immediate decisionmaking, and (3) to analyze the SFC/DC data to feed long-term analysis models. The objective of these analysis activities is to reduce or eliminate delays on the shop floor and to gain a better understanding of floor activities.

The effort has been broken into three phases: (1) understanding the configuration of the SFC/DC database, (2) "learning" the actual values being stored in the database and prototyping some of the proposed methods, and (3) further developing the prototypes from Phase 2 and full development of new methods and tools for continuous analysis. Phase 3 seeks to develop a Shop Floor Modeling, Analysis, and Reporting Tool (SMART) system. SMART is a framework designed around a database that will contain statistical information regarding work time, delay duration, and other relevant inferential and descriptive information. This framework was devised under the premises that it has to be easy to use and flexible to allow growth of KSC's modeling activities. It must be pseudointelligent to provide guidance to end users and it has to be an open system to avoid "re-inventing the wheel" by integrating off-the-shelf products. Modules of SMART include an Expert Assistant (a knowledge-based system that will be a tutor and an assistant to KSC engineers regarding statistical analysis techniques) and a Knowledge-Based Analysis system that will generate descriptive statistics, estimate variables of interest, conduct various correlation analyses, conduct various hypotheses testing on the similarity of facilities, compute various joint probability functions for delay duration, enable the collection of historic behavior for future use in other modeling activities, and generate interpreted reports.

The implementation of SMART calls for statistical analysis models that yield robust results even with small sample sizes. Many of the stochastic models developed for general manufacturing and assembly processes are based on the limiting distribution of the variables under study. However, the limiting distributions are realized when the size of the samples used in estimation is large. Shuttle processing and other high-technology environments fail to generate these large sample sizes; therefore, an investigation is planned to determine how existing methods could be modified so they can be used in this type of environment.

Key accomplishments:

- 1993: Understanding of the accessibility of the SFC/DC database, consensus of the completeness of data, and an understanding of the data exchange process. Specific data extraction protocols have been implemented. Initial evaluation of various tools (commercial off-the-shelf databases, spreadsheets, programming languages, statistical packages) as potential development tools for SMART was undertaken.
- 1994: Prototyping of a data exchange interface to feed spreadsheet templates and the Schedule/Cost Risk Analysis Management (SCRAM) system. A set of spreadsheet templates that, in conjunction with programming routines, enables the generation of inputs for SCRAM, multiple flows descriptive statistics of tasks worked, monitoring of the SFC/DC data entry process, and descriptive statistics for stoppages.

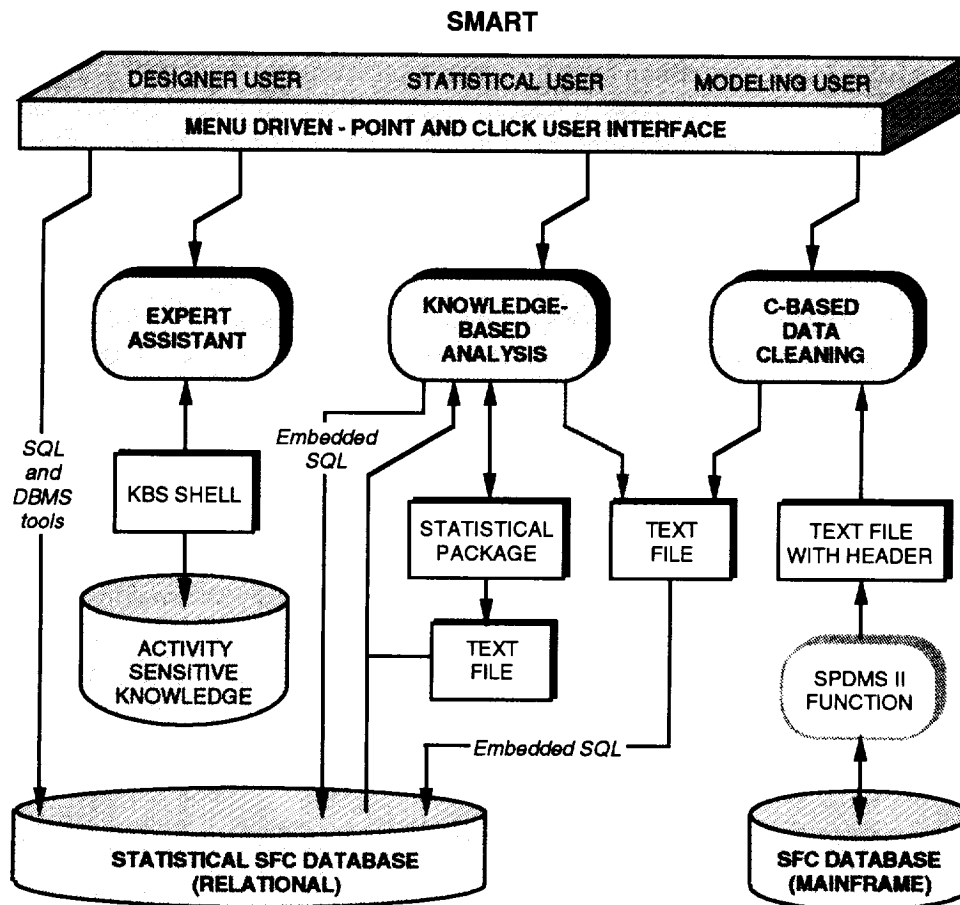


Key milestones:

- 1995: Extensive statistical analyses of delay and task information in the SFC/DC; further evaluation of COTS software tools.
- 1996: Development of modeling techniques; prototype of SMART.
- 1997: Initial implementation of SMART.

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Participating Organization: Florida International University (M. Centeno)



Shop Floor Modeling, Analysis, and Reporting Tool

Optimization of Stochastic Resource-Constrained Project Schedules

Ideally, project managers would like to develop the “best” or optimal schedule for their project. This is relatively straightforward if one assumes known task durations and unlimited resources. Any number of commercial project-scheduling software can be used to solve this problem. The problem becomes much more difficult if resources are limited — the resource-constrained problem. Methodologies for finding the optimal solution to the deterministic resource-constrained project-scheduling problem are well known but computationally intractable; one must resort to either heuristics or manual user input (as all commercial software does) to find a “good” feasible solution. Researchers have not yet identified the theoretical basis for the optimal solution to the stochastic resource-constrained project-scheduling problem. The present study seeks to develop the theoretical foundation for the optimal solution of this problem and to begin development of heuristics and other approximating techniques for solving practical problems.

Solutions to the stochastic resource-constrained project-scheduling problem can be found using either the expected value of task durations or anticipative techniques. Use of the expected value of task durations simplifies the problem but does not guarantee optimality. Anticipative techniques rely on information unavailable to the decisionmaker at the time the decision is made. These approaches are clearly nonimplementable since they anticipate all task durations for each specific project realization and rely on unknown joint conditional probabilities of task durations. A project manager would be at a loss if asked to make actual scheduling decisions based on anticipative techniques.

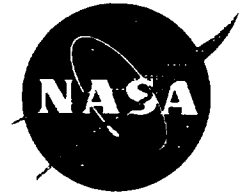
The present study seeks to develop the nonanticipative optimal solution to the problem using a decision theoretic approach. The project started in September 1993 with the award of a NASA Graduate Student Research Fellowship. The 1993 to 1994 academic year was dedicated to a literature search and problem formulation. The September 1994 to August 1995 time period will be used to develop the concept of the optimal solution to the stochastic resource-constrained project scheduling problem. The principal elements of this concept are stochastic relationships between the various optimal solutions to the constrained problem. The figure “CDF Optimal Solutions” illustrates these relationships for a sample problem. The cumulative distribution function (CDF) of the unconstrained problem, shown as curve 1 in the figure, is at least as small in distribution as any feasible solution to the constrained problem. The CDF of the optimal anticipative solution to the constrained problem, shown as curve 2, is at least as small in distribution as any feasible nonanticipative solution to the constrained problem. Finally, the CDF of the optimal nonanticipative solution to the constrained problem, shown as curve 3, minimizes the regret of not being able to predict the task durations. Curve 4 shows a possible nonanticipative feasible solution to the constrained problem, exhibiting larger regret than the optimal solution.

Key accomplishments:

- 1993: NASA Graduate Student Research Fellowship awarded; literature search and problem formulation.
- 1994: Definition of optimality for both the anticipative and nonanticipative solutions.

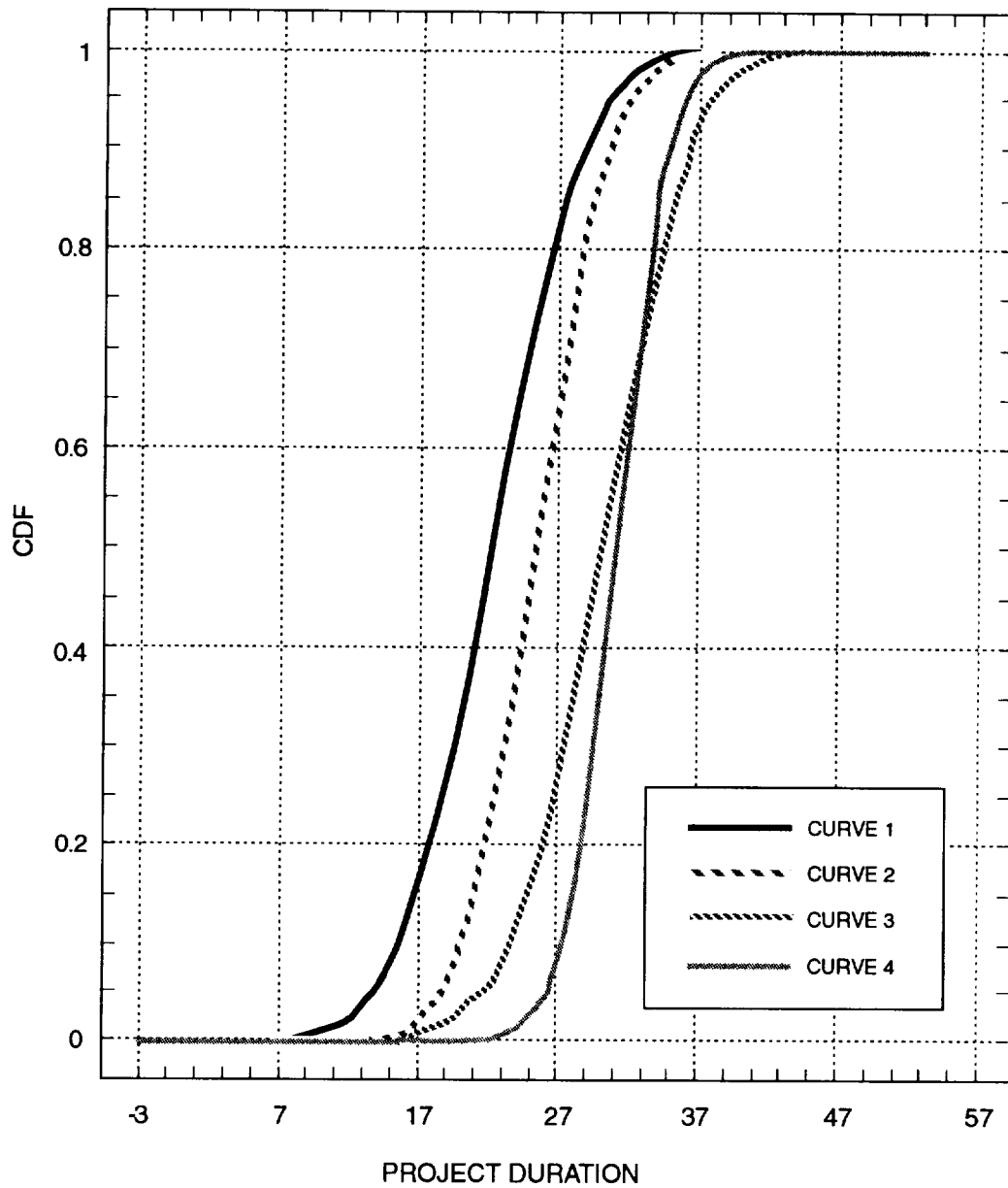
Key milestones:

- 1995: Prove the stochastic relationships between the nonanticipative optimal solution and other possible optimal solutions.



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Participating Organization: University of Central Florida (A. Fernandez)



CDF Optimal Solutions

Automated Recertification Training System

1994 marked the completion of Phase II of a Small Business Innovation Research (SBIR) project by ENSCO, Inc., to enhance the computer-based training (CBT) process at KSC. The primary focus for this improved training approach was the periodic recertification of technicians to perform specific Shuttle processing tasks. Phase I of the Automated Recertification Training System (ARTS) project began in 1991 to perform applied research toward the conversion of existing certification courses to CBT. While CBT has been available for many years, improvements in the development and delivery process were needed to allow production of CBT courseware on a larger scale to meet KSC's recertification training needs. ENSCO's goal was to apply improved software development methodology along with multimedia technology to increase the efficiency and cost-effectiveness of CBT.

The technical approach taken in Phase II was to streamline the traditional instructional development model into a process for more rapid development of CBT courseware. The "new" process is illustrated in the figure "Courseware Production Process." The process contains the same overall phases of the traditional model (Analysis, Design, Development, and Evaluation), with three key distinctions:

1. A "micro needs analysis" procedure was established for modification of the existing classroom training materials for CBT, while focusing on recertification and just-in-time reference requirements of Shuttle technicians.
2. CBT design standards were developed to facilitate production and maintenance of CBT applications that were compatible with design practices being used at KSC.
3. A CBT development shell was used containing production tools and templates extending the capabilities of Asymetrix™ ToolBook™, a commercial authoring package (see the figure "CBT Development Shell").

Upon the completion of Phase II in May 1994, the following results were achieved:

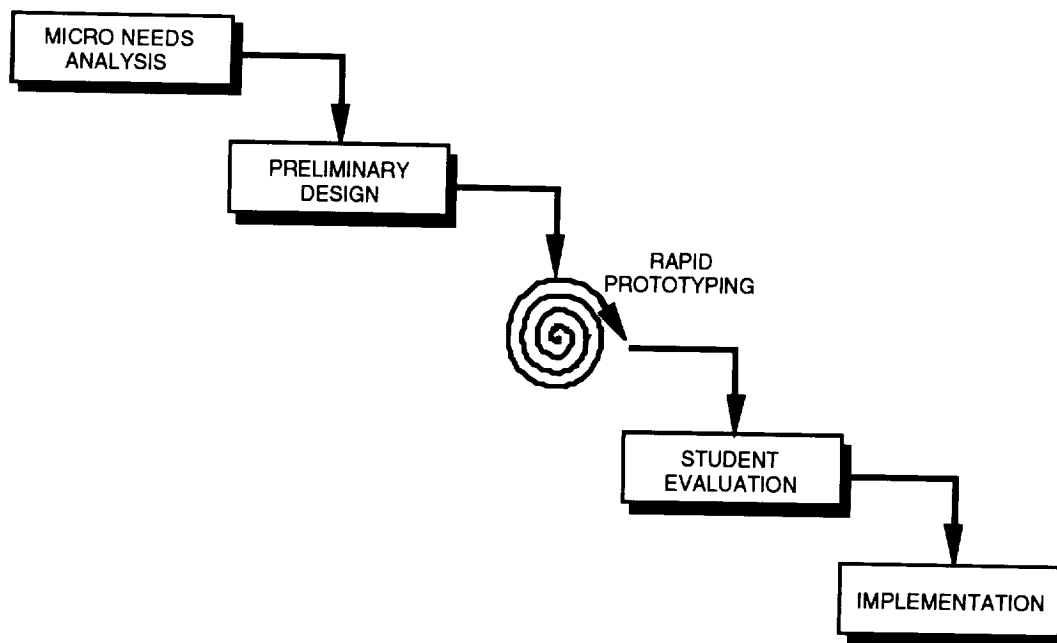
1. Five pilot CBT courses at varying levels of sophistication were delivered to KSC and will be incorporated into the Shuttle processing training curriculum.
2. Field testing of pilot courses showed training time reductions of up to 50 percent over classroom-based methods and a 10 to 20 percent improvement in pretest/posttest scores.
3. Reduction in CBT development time using the ENSCO development shell and design standards is estimated to be 30 to 60 percent, depending on course complexity.
4. Research into network delivery of CBT utilizing digital audio/video revealed several emerging technologies that will greatly improve CBT availability within 2 to 3 years.

Future plans for Phase III of this SBIR project are to transfer CBT technology to other Government agencies and commercial firms. The primary focus of the follow-on effort includes technical training in aerospace applications and embedding CBT applications in high-end software systems. Additional research is also being conducted by ENSCO into advanced CBT distribution methods (such as CD-ROM and high-speed networks) suitable for multimedia content.

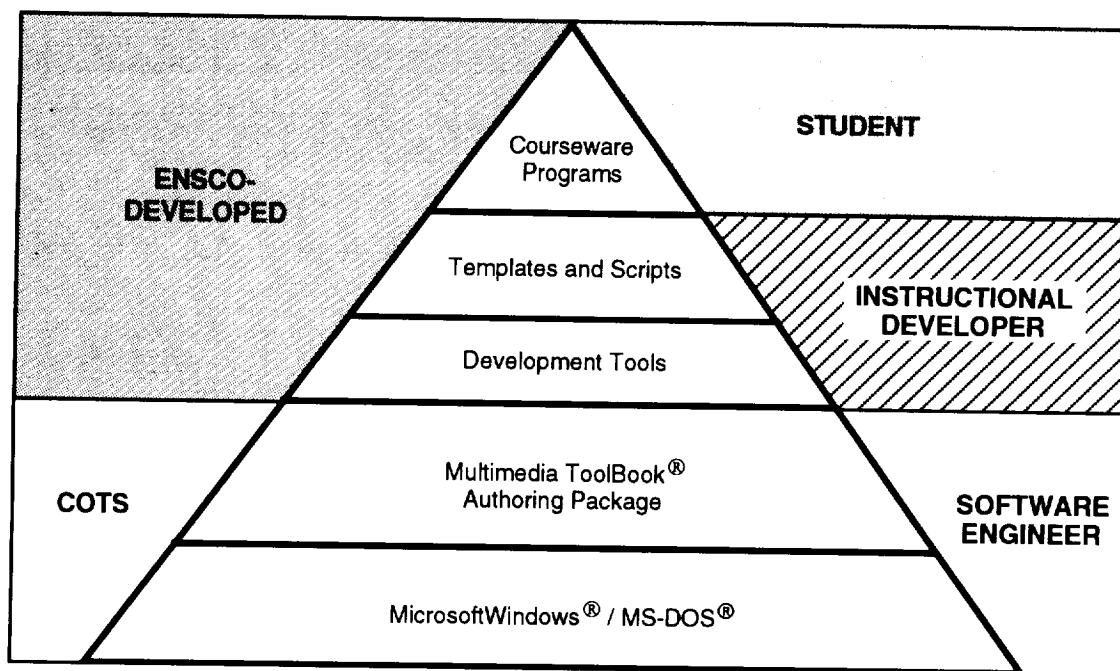


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Participating Organization: ENSCO, Inc. (G. Drapé)



Courseware Production Process



CBT Development Shell



The John F. Kennedy Space Center (KSC) is located on the Merritt Island National Wildlife Refuge. Therefore, KSC has always approached its mission with an awareness of the impact on the environment. As a society, Americans have become increasingly concerned about the effect their actions have on the environment. With this awareness, KSC has increased its efforts to develop technologies that are environmentally oriented and proactive.

The projects presented this year cover a wide range of environmental technologies. Engineers are developing effective methods of cleaning without the use of chlorofluorocarbons. Several development efforts are underway that address the safety and disposal of the hazardous fuels used in launch vehicles and satellites.

Another area of interest is the geographical information required to make environmental decisions. A development is continuing to integrate geographical databases that provide easy access to the data used for planning purposes.

Environmental Technology

Threatened and Endangered Species Monitoring

The 57,000 hectares of KSC represent an area of biological diversity unsurpassed among other Federal facilities within the continental U.S. Approximately 100 wildlife species on the Merritt Island National Wildlife Refuge are in danger of declining population size and/or extinction. Under the requirements of the Endangered Species Act and the National Environmental Policy Act, each new construction project and ongoing operations at KSC must be evaluated to ensure impacts to these species and their habitat are minimized.

To address this growing concern, a ranking system was developed, based on: (1) a species' vulnerability in the U.S., in Florida, and at KSC and (2) the relevancy of KSC for maintaining U.S. and Florida populations. Studies are conducted on priority species to develop predictive and interpretive abilities regarding the ecology of their populations. Currently, program activities focus on species listed by regulatory agencies. These include marine turtles, manatees, scrub jays, wading birds, shore birds, indigo snakes, gopher tortoises, and southeastern beach mice.

Key accomplishments:

- 1991: Developed habitat maps of the most important areas on KSC for manatees, scrub jays, wading birds, and other species.
- 1992: Developed a scrub restoration and monitoring program.
- 1993: Developed a wetlands restoration program.

Key milestones:

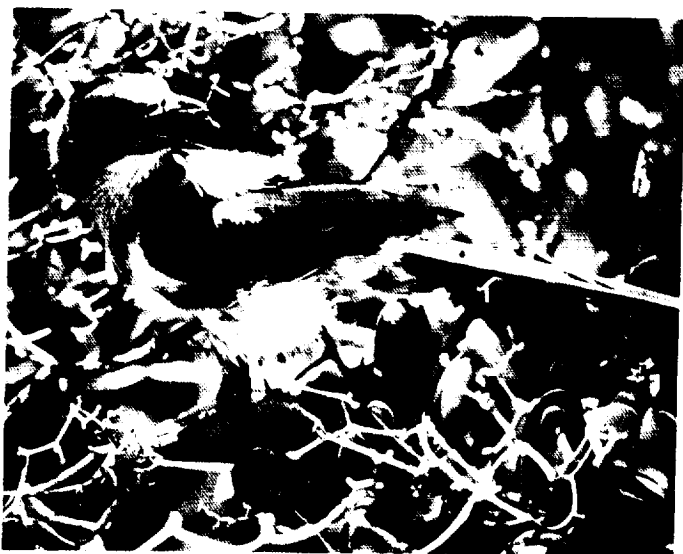
- 1994: Complete the study on threats to biological diversity. Implement the wetlands mitigation and restoration program.
- 1995: Complete analyses of several priority species studies.

Contact: W.M. Knott, Ph.D., MD-RES, (407) 853-5142

Participating Organization: The Bionetics Corporation (D.R. Breininger)



*Releasing an Indigo Snake With
Radio Transmitter*



Scrub Jay, a Federally Listed Species, on KSC



*Federally Protected Wood Storks Feeding Near
Launch Pad 39A*

Organic Analytical Chemistry Research

The organic analytical chemistry laboratory continues to develop and refine analytical methods with a focus on KSC's Biomass Production Chamber (BPC). Characterizations of organic constituents continue from plant growth chamber atmospheres, nutrient solutions, condensate waters, plant leachate solutions, and plant tissues. The quantification and elucidation of biogenic emissions from plants are significant in understanding the carbon balance within a closed plant growth chamber. More efficient crops with a minimum of carbon lost in volatilization will contribute to the optimization of food production. Elevated concentrations of a naturally occurring plant hormone, ethylene, in the BPC may be correlated with physiological effects for both wheat and potatoes. Root exudates, biogenic plant emissions, and leachate materials from the inedible portions of the plants may play a role in phytotoxicity and allelopathy.

Monitoring the BPC for atmospheric ethylene concentrations is supported by a portable gas chromatograph with a photoionization detector. Investigations continue to correlate ethylene production with biomass increase and morphological changes in plants.

Methods of headspace analyses by gas chromatography/mass spectrometry (GC/MS) are being refined for quantification of biogenic and anthropomorphic contaminants in atmospheric samples. Extraction and high-performance liquid chromatography methods for characterization of plant leachate materials, sugars, and plant growth regulators continue.

Further studies to target source and phytotoxic and allelopathy effects of organic components from plant growth chamber materials and reagents are needed. The laboratory continues with the characterization of leachate studies. Automated methods for monitoring organic contaminants are being investigated.

Key accomplishments:

- 1989: Developed the laboratory.
- 1990: On-line ethylene studies.
- 1991: GC/MS analysis of volatile organics in a BPC condensate water and nutrient solution.
- 1992: Developed methods for biogenic emission measurements. Compared air-sampling technologies for GC/MS studies. Developed an analytical method for the characterization of volatile organic contaminants from reagents and BPC construction materials. Developed an analytical method for the characterization of biogenic emissions from plants.
- 1993: Compared air-sampling techniques with an ion trap and quadrupole mass spectrometer for air analysis. Developed an extraction technique for analysis of polyphenols in leachate materials. Completed the characterization of trace organic constituents in potato and wheat crop atmospheric studies. Completed a preliminary database for 4 years of ethylene output profiles with soybean, potato, wheat, and lettuce crops.
- 1994: Characterized the atmosphere from leachate studies. Continued with the characterization and monitoring of trace volatile constituents in the BPC atmosphere for the white potato study.



Key milestones:

- 1994: Moved the chemistry laboratory into a new facility. Published "Sparging Technique for Biogenic Emissions," NASA Technical Memorandum 109100. Published "Biomass Production Chamber Air Analysis of Wheat Study," NASA Technical Memorandum 109192.

Contact: J.C. Sager, Ph.D., MD-RES, (407) 853-5142

Participating Organization: The Bionetics Corporation (B.V. Peterson)

Continuation of the Qualification of Fourier Transform Infrared (FTIR) Instrumentation for the Launch Pad Environment

Processing of Space Shuttle vehicle and payloads involves the handling of many volatile materials, some are highly reactive and toxic while others are not. The toxic materials used on the Shuttle include monomethylhydrazine (MMH) fuel and dinitrogen tetroxide (N_2O_4) oxidizer. In addition to monitoring for leaks of toxic materials, the instrumentation must be insensitive to nonhazardous materials such as alcohols or other solvents. The toxic vapors are to be measured at very low concentrations, often in the presence of much higher concentrations of nonhazardous vapors. Previous work shows that FTIR-based instrumentation is capable of monitoring the environment for these materials, but instrumentation of this type had not been used in the vibration and acoustical noise environment of a Space Shuttle launch before 1994. In order to demonstrate the suitability of FTIR for permanent installation on the launch pad, it was necessary to place several instruments in a cabinet on the pad during a Shuttle launch.

Preliminary tests with dummy weights using accelerometers and microphones indicated that both vibration and acoustic isolation would be required to protect the FTIR optics and electronics from the launch environment. Process-monitoring FTIR instruments of three different designs were purchased from three different manufacturers for evaluation on the launch pad. The three FTIR's were equipped with long path gas cells and embedded computers capable of performing the required quantitative vapor analysis. The FTIR's were installed in a cabinet that provided acoustic isolation in the walls and structural vibration isolation for each instrument, as well as nitrogen purge for each instrument. The cabinet and FTIR's, along with sample system and computer components, were installed on Launch Complex 39, Pad B, for the launch of STS-61.

Prelaunch and postlaunch evaluations of each of the FTIR's demonstrated they suffered no detectable damage during the Shuttle launch. Software was developed to analyze the analytical performance of the FTIR's and was used to evaluate the signal-to-noise ratio of the FTIR's. One model was selected based on performance tests. A subsequent test on the Shuttle launch pad used three of the selected model FTIR's, and no detectable damage occurred. The same units have been in operation both in the laboratory and in the field with no hardware failures for 8 months.

Key accomplishments:

- Environmental protection for FTIR's during Shuttle launch was demonstrated.
- Three types of FTIR's in actual launch conditions were tested (all passed).
- Statistical evaluation of FTIR performance was completed.
- One type of FTIR based on performance (speed, resolution, and analytical performance) was selected.
- Test using three of the selected FTIR's for one more Shuttle launch was repeated.

Key milestone:

- Technology applied to monitoring of Shuttle tile waterproofing material and to monitoring ammonia for the Space Station Processing Facility.

Contact: D.E. Lueck, DL-ICD-A, (407) 867-4439

Participating Organization: I-NET Space Services (C.B. Mattson and T.A. Hammond)



Hypergol Vapor Detection System Equipment Rack

Advanced Life Support System Evaluations

Advanced life support is a critical technology for long-duration manned spaceflight, whether in low Earth orbit, on the Moon, on Mars, or beyond. There are a number of viable options for most of the life support functions. These options must be evaluated and a selection made for any particular mission. In addition, trade studies must be made on where to provide research and development funding based on probable return.

In 1994, a detailed concept of a Controlled Ecological Life Support System (CELSS) module for a four-person lunar base was developed, based on CELSS breadboard data and data from other sources. In particular, breadboard data was assessed to evaluate mass flow within a CELSS. The data included plant growth, bioreactor, and equipment data.

The concept was developed as a three-dimensional, computer-aided design model that can be used for access and operational studies, including an evaluation of robotic and crew operations. The concept provides approximately an 80-square-meter plant growth area, assumes flat-plate lighting, uses a gantry robot for physical automation to minimize crew time requirements, and provides for atmospheric composition control and waste treatment/resource recovery.

CELSS module equivalent mass has been recalculated based on new data. The concept included using mixed red and blue light-emitting diodes (LED's) to estimate mass and volume impacts. While recognizing that blue LED's are still too inefficient and that photomorphogenic effects may be a problem, LED lighting has several attractive features: the efficiency is fairly high, the canopy heating is low, the volume required is low, and the lifetime is excellent. In comparison, high-pressure sodium lamps are more efficient but, with the required reflectors and thermal filters, are quite large; they cause significant heating of the canopy, which leads to higher requirements for airflow.

Better data on the cost of heat rejection on the Moon has shown that heat rejection from a CELSS to the lunar environment during the lunar day is a major cost driver in some scenarios due to the low-grade heat to be rejected and the high sink temperature. This makes it more attractive to use sunlight directly for plant irradiance, despite the engineering difficulties of getting light into the module under a radiation shield of regolith. Light guides and fiber optics seem attractive, but estimates of mass are not reliable due to the need for technology development in that area. Artificial lighting would be needed during the lunar night but could be distributed through the same system.

Since light distribution typically involves significant losses, the light system should be kept close to the canopy. This can easily be achieved by adjusting the light panels to a minimal distance from the canopy, at least with low-mass panels.

Significant reductions in equivalent mass are possible from current state of the art. A fill-and-drain nutrient delivery system concept has been developed that would reduce the mass of plumbing and fluid reservoirs. The nutrient fluid may also be used for cooling if LED's are used, though the temperature rise would have to be limited to about 1 degree. The air exchange rate can be greatly reduced if infrared canopy heating is minimized. Airflow normal to the canopy, rather than across it, would also be more efficient.

As the plant growth system is the major part of a CELSS module, the design of a 1-square-meter plant growth area was further evaluated. All inputs and outputs were identified, including mass and data.



Key accomplishments:

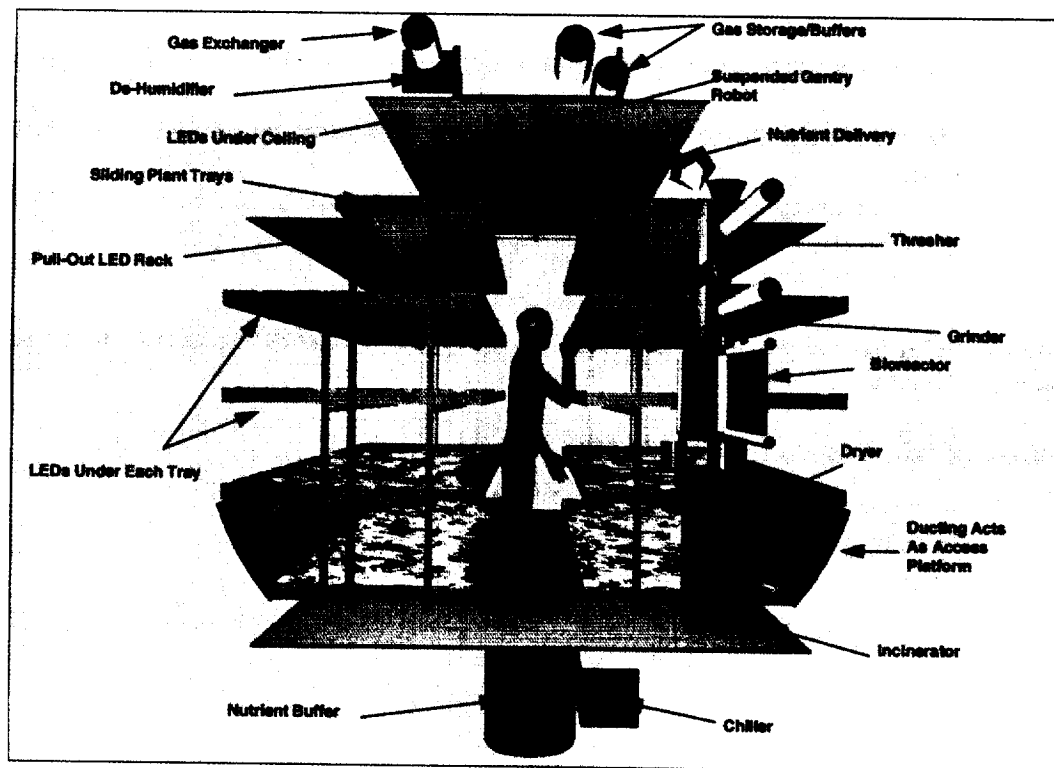
- 1991: Developed an equivalent mass approach and a CELSS computer model.
- 1992: Enhanced the CELSS model. Performed trade studies on different CELSS and PC scenarios, including different resource recovery options.
- 1993: Began to perform PC trade studies. Continued using the equivalent mass approach to evaluate CELSS options and define Phase 2 of the CELSS breadboard project. Developed the CELSS Monitor and Control Implementation Plan.
- 1994: Began sizing of a CELSS based on previous work and identifying resource requirements. Developed a monitor and control system specification based on the existing system. Continued evaluations of PC technology.

Key milestones:

- 1995: Begin detail design of Phase 2 of the CELSS breadboard facility with a focus on approach more closely to a flight-like configuration. Evaluate methods for providing multiple crop environments and for lighting. Evaluate advanced automation technologies appropriate for the Advanced Launch System, including the prototype development.

Contact: J.C. Sager, Ph.D., MD-RES, (407) 853-5142

Participating Organization: McDonnell Douglas Space Systems (Dr. A.E. Drysdale)



Water Quality Inventory for Mosquito Lagoon

The water quality and ecology of Mosquito Lagoon and the Canaveral National Seashore have been the focus of a 3-year interagency study. NASA and the National Park Service use this study to help in developing a long-term monitoring program to ensure protection of this unique natural resource for future generations.

A comprehensive computerized literature and information database was developed of organizations and agencies conducting sampling in the area. Information gaps were identified, and a collection of 2 years of site-specific data was completed. These data are being summarized into a technical report, and a long-term monitoring program for implementation by Canaveral National Seashore personnel is being developed.

The 2-year baseline database includes information on water and sediment chemistry, seagrass distribution and abundance, demersal fish population characteristics, and light attenuation. The extensive underwater light field data set focuses on photosynthetically active radiation and factors that influence backscattering, absorption, and attenuation. Light fields control the distribution and magnitude of primary production and are known to be influenced by man's activities such as watershed development, stormwater runoff, and sewage disposal through the addition of nutrients and particulates.

Key accomplishments:

- 1990: Interagency agreement initiated. Literature survey and computerized database developed.
- 1991: Progress report and Phase II sampling plan completed and approved. Field data collection initiated.
- 1992: Mosquito Lagoon Environmental Resource document published. Fish community sampling completed.
- 1993: Water quality inventory, underwater light attenuation, and seagrass bed mapping completed. Final analyses begun.
- 1994: Monitoring program developed. Final reports and recommendations submitted.

Key milestone:

- 1995: Assist the Canaveral National Seashore with the implementation of a monitoring program for North Mosquito Lagoon.

Contact: W.M. Knott, Ph.D., MD-RES, (407) 853-5142

Participating Organization: The Bionetics Corporation (J.A. Provancha and R.H. Lowers)



Spherical Quantum Sensor for Measuring Light Attenuation in Mosquito Lagoon



Fish Samples Collected in Mosquito Lagoon



Field Positioning of a Programmed Water Quality Data Collector

Air Quality Monitoring

For pollutants assigned priority by the Environmental Protection Agency (EPA) and the Florida Department of Environmental Regulation (DER), long-term ambient monitoring is conducted to fulfill the requirements of the National Environmental Policy Act commitments made in the KSC Environmental Impact Statement and to provide data for use in permitting, compliance, and impact analysis.

The monitoring of priority pollutants, including ozone, sulfur dioxide, carbon monoxide, nitrogen dioxide, and particulates, as well as local meteorological conditions continued at the permanent air monitoring station (PAMS) site. Instrumentation used for sampling employs different analytical techniques including ozone (ultraviolet absorption), sulfur dioxide (pulsed ultraviolet fluorescence), carbon monoxide (gas filter correlation infrared absorption), and nitrogen oxides (gas chemiluminescence). The data are collected once per minute by a Hewlett Packard 9000 series mainframe computer and validated using the EPA and DER quality assurance guidelines. There were no exceedances of the Federal or state air quality standards during the year for the KSC area.

Accomplishments during the year included installation of new samplers to monitor inhalable particulates (PM-10), acquisition from the U.S. Air Force of a spatial database on historic rainfall volumes for KSC, initial screening of light hydrocarbons in the ambient air environment, and collection of samples of Shuttle exhaust particulates for determination of trace metal constituents. Sampling of ambient volatile organic (VOC) compounds with a portable gas chromatograph will allow for a more complete assessment of fates of VOC's released into the atmosphere from permitted facility operations. Identification of VOC's released by plants will allow for development of models of carbon cycling in the ecosystem and possible identification of ecosystem responses to man-made disturbances.

Key accomplishments:

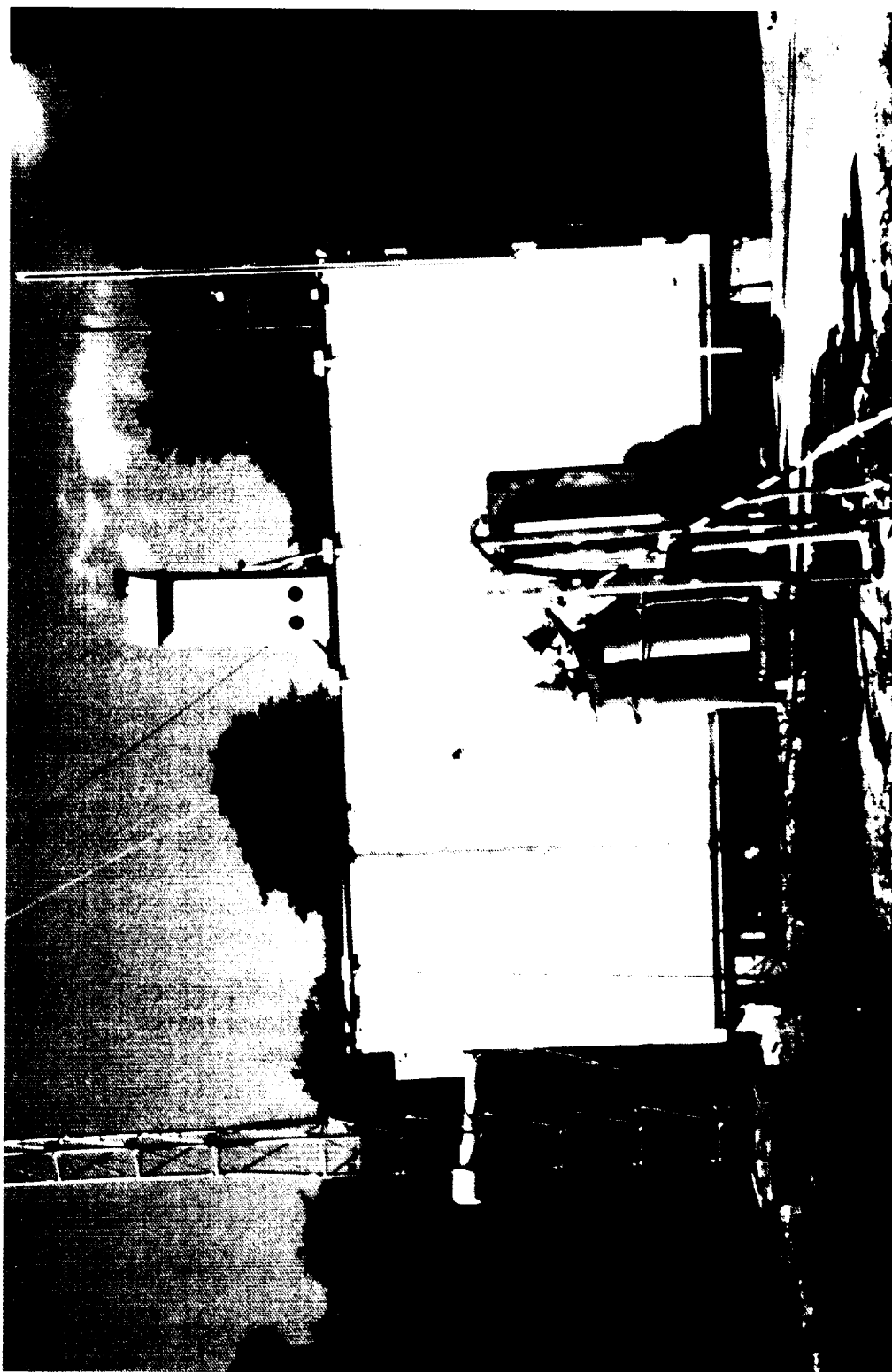
- 1991: Acquisition and installation of the new replacement trailer and the new monitors for ozone and nitrogen dioxides.
- 1992: Acquisition of new PM-10 monitors and a portable gas chromatograph.
- 1993: Deployment and use of the PM-10 monitors and the portable gas chromatograph. Began looking at the spatial distribution of rainfall data for KSC.
- 1994: Continued monitoring of the ambient criteria pollutants and began KSC-wide monitoring of light hydrocarbons and other VOC's. Also, continued monitoring inhalable particulates at two sites on KSC. Completed the summary document for the long-term air monitoring data. Attended training in air dispersion modeling.

Key milestones:

- 1995: Continue monitoring of the above pollutants. Begin analysis of the VOC data. Begin air dispersion monitoring.

Contact: W.M. Knott, Ph.D., MD-RES, (407) 853-5142

Participating Organization: The Bionetics Corporation (J.H. Drese)



Permanent Air Monitoring Station

**Fourier Transform Infrared (FTIR) Instrumentation To Monitor Vapors
From Shuttle Tile Waterproofing Materials**

The Space Shuttle Thermal Protection System (TPS) tiles and blankets are waterproofed using dimethylethoxysilane (DMES) in the Orbiter Processing Facility (OPF). DMES has a threshold limit value (TLV) for exposure of personnel to vapor concentration in air of 0.5 part per million. The OPF high bay cannot be opened for normal work after a waterproofing operation until the DMES concentration is verified by measurement to be below the TLV. On several occasions, the high bay has remained cleared of personnel for up to 8 hours due to high DMES-concentration measurements made using Miran 203 infrared analyzers calibrated at various wavelengths. In addition, the different wavelength instruments gave different readings under the same conditions. There was reason to believe some of the high DMES-concentration readings were caused by interference from water and ethanol vapors. The task was to verify the DMES measurements after the completion of a waterproofing operation.

An FTIR spectrophotometer instrument developed for the Hypergol Vapor Detection System II was reprogrammed to measure DMES vapor along with ethanol, water, and several common solvent vapors. The FTIR was then used to perform a series of laboratory and field tests to evaluate the performance of the single-wavelength infrared (IR) instruments in use. The results demonstrated the single-wavelength IR instruments did respond to ethanol and water vapors, more or less depending on the analytical IR wavelength selected. The FTIR was able to separate the responses to DMES, water, and ethanol and give consistent readings for the DMES vapor concentration. The FTIR was then deployed to the OPF to monitor real waterproofing operations and was also used to measure the time for DMES to evaporate from the TPS tiles under a range of humidity conditions in controlled laboratory tests.

The combination of laboratory and field tests with the FTIR instrument demonstrated a superior sensitivity, the ability to reject interference from water and ethanol vapors, and the ruggedness required to be transported from the laboratory to the OPF and be set up without special procedures or degradation of performance. Based on the successful demonstration of capabilities, a permanent, mobile instrument cart to be used in each OPF to support future waterproofing operations is proposed. The design and building of the DMES carts are scheduled for fiscal year 1995.

Key accomplishments:

- Demonstrated the ability of the FTIR instrument to measure DMES vapors.
- Demonstrated the ability to separate DMES from water and ethanol vapors.
- Measured times for DMES to evaporate from Shuttle tile samples.
- Supported 10 waterproofing operations in the OPF.
- Supported OPF ventilation tests to remove residual DMES vapors.
- Proposed a system for using the FTIR to monitor DMES vapor in the OPF.

Key milestones:

- Design and build three FTIR-based systems to monitor DMES vapors for the three OPF's.

Contacts: D.E. Lueck, DL-ICD-A, (407) 867-4439, and P.A. Mogan, DL-ICD-A, (407) 867-9167

Participating Organization: I-NET Space Services (C.J. Schwindt and C.B. Mattson)



Tile DMES Off-Gas Testing

Hypergolic Oxidizer and Fuel Scrubber Emission

The emissions from the hypergolic propellant scrubbers at KSC are difficult to measure due to the intermittent flow and the environment, which is wet with propellant and/or scrubber liquor. An alternate method to measure these emissions was examined that did not require measurement of the flow rate or concentration. This new approach is based on scrubber efficiency (which was measured during normal operations) and the accumulated weight of the hypergol captured in the scrubber liquor (this information is available as part of the routine monitoring of the scrubber liquors). To validate this concept, a study was initiated for which the primary objective was to determine if the emissions from hypergolic propellant scrubbers at KSC could be calculated from the propellant buildup in the scrubber liquor and from the scrubber efficiency. In support of this objective, a log of the propellant buildup for each KSC scrubber was prepared; the efficiencies of the KSC scrubbers during normal operations were measured; and an estimate of the annual emissions, based on the efficiencies and the propellant buildup data, was made. In addition to the primary objective, data were collected on mist generated at the fuel scrubbers, the stability of the hypergols in their scrubber liquors, and the emissions of hydrazine and/or monomethylhydrazine (MMH) generated by the neutralization of used scrubber liquor with sodium hydroxide. Also, analytical methods were adapted for this application, and a hypergol vapor scrubber monitor was designed and built.

This study consisted of qualification tests to validate the new monitoring method and measurement of the efficiencies for the scrubbers at Launch Pads 39A and 39B and the Orbiter Processing Facility (OPF) Bays 1, 2, and 3. This new method is based on (1) accurate measurements of the scrubber efficiency (EFF) for each type of operation, (2) an estimate of the number of operations and their contribution to the total annual flow through the scrubber, and (3) a measure of the concentration change of fuel or oxidizer reacted with the scrubber liquor. The concentration change of the component of interest in the scrubber liquor before and after an operation is used to calculate the emissions.

$$\text{Emissions (wt.)} = [(1/\text{EFF}) - 1] \times \Delta (\text{wt. of hypergol})$$

The data have demonstrated that the emissions from the KSC scrubbers can be monitored by measuring the buildup of hypergolic propellant in the scrubber liquors and then using the appropriate efficiency to calculate the emissions. Three qualification tests were conducted on the two types of fuel scrubbers and the oxidizer scrubber at the propellant storage farms. There was good agreement between the calculated emissions based on the outlet concentration, the flow rate, and the time and the calculated emissions based on the propellant buildup and the efficiency. The efficiencies of the scrubbers at KSC were measured [except for the scrubbers at the Hypergolic Maintenance Facility (HMF), which were estimated]. The total gas flow rate is the primary factor that affects scrubber efficiency. The field tests also uncovered a significant amount of mist issuing from the fuel scrubbers, which contains the citrate salt of the fuel. The concern about the mist is that it will release the fuel when the pH is increased above 6.

Key accomplishments:

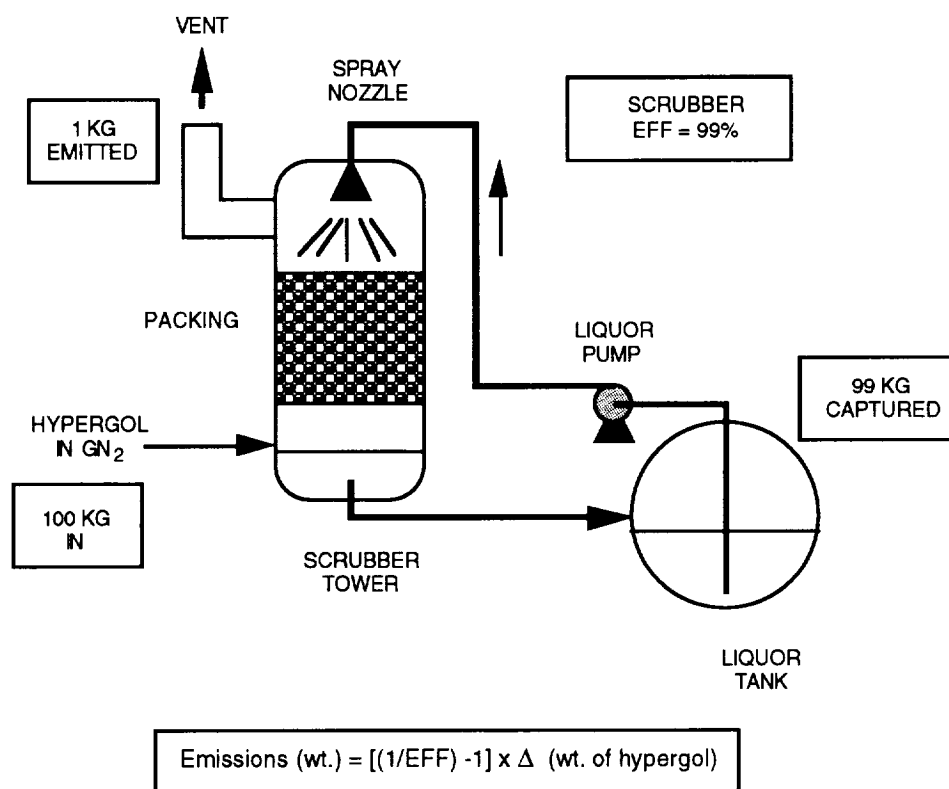
- A new method to measure emissions from the KSC scrubbers has been validated.
- The efficiencies of the KSC scrubbers at Launch Pads 39A and 39B and OPF Bays 1, 2, and 3 have been measured under normal operating conditions, and the efficiencies of the HMF scrubbers have been estimated.



- A log of the propellant buildup and an estimate of the emissions for all KSC scrubbers over the past 3 years have been prepared.
- Mist emissions from the KSC fuel scrubbers have been confirmed and found to contain MMH.
- A hypergolic vapor scrubber monitor was constructed and used to measure the efficiencies of the hypergol propellant scrubbers.

Contacts: R.C. Young, DE-EMO, and D.E. Lueck, DL-ICD, (407) 867-4439

Participating Organization: I-NET Space Services (C.F. Parrish and R.G. Barile)



Toxic Vapor Scrubber Emissions Monitoring Concept

Emissions From Neutralization of Fuel Scrubber Liquor

Concern about fuel scrubber liquor mist and the potential for the release of monomethylhydrazine (MMH) or hydrazine (HZ) from the scrubber liquor poses a potential environmental and health risk. Therefore, this study was initiated to estimate the potential for MMH or HZ release during the neutralization of spent fuel scrubber liquor (initially 14-percent citric acid) with sodium hydroxide and to determine the capacity of the fuel scrubber liquor for MMH below a pH of 7. Three tests were performed during this study. First, the pH of used scrubber liquor was adjusted to 4 and then to 7, and the MMH content was measured. Second, sodium hydroxide was added to the spent scrubber liquor (pH range 2.88 to 11), and the emissions of MMH were measured. Third, a 14-percent citric acid solution was titrated with MMH, and the percent of MMH was calculated.

The content of the MMH was determined in the initial sample, after an adjustment to a pH of 4 and after an adjustment to a pH of 7 with sodium hydroxide. The emission rate was measured with a calibrated ESI 7660 MMH detector as a function of pH. The relative emissions in ppm-seconds at a given pH were calculated as the product of the concentration in parts per million (ppm) and the time in seconds.

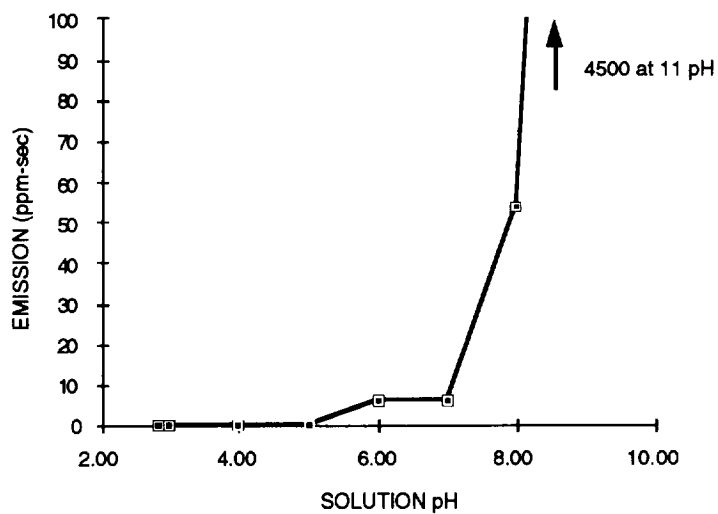
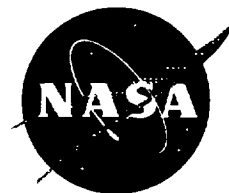
The change in the concentration of MMH in a used citric acid scrubber liquor was measured as the pH was increased. The initial concentration of MMH, 4.05 milligrams per milliliter (mg/mL), decreased to 2.55 mg/mL for a pH of 4 and to 2.19 mg/mL at a pH of 7. Monomethyl hydrazinium citrate will release MMH when it is reacted with sodium hydroxide and the quantity is influenced by the local pH. Although the experiment was not designed to measure the total gaseous emissions from the neutralization process, the data in the figure "MMH Emissions During Neutralization With 5N Sodium Hydroxide" shows that the onset of the release of gaseous MMH occurs around a pH of 6 and that the emissions increase rapidly as the pH is increased to 9 or greater. These results suggest that care should be exercised when used scrubber liquors are neutralized to minimize low local pH values. When a 14-weight-percent solution of citric acid is titrated with MMH, there is the potential for the addition of 3 moles of MMH to each mole of citric acid, since citric acid has three carboxylic acid functional groups. The figure "Potentiometric Titration of 14-Weight-Percent Citric Acid With MMH" shows an inflection point at a pH of 6.4 and a second point at approximately 8.4 pH. The first inflection point at pH 6.4 corresponds to the neutralization of one of the carboxylic acid functions on citric acid. The second inflection at approximately 8.4 pH corresponds to the reaction of the second carboxylic acid function on citric acid. Therefore, the capacity of the 14-weight-percent citric acid scrubber liquor would be 3.35-weight-percent MMH for a scrubber liquor pH of 6.4. This means that 650 gallons of 14-weight-percent citric acid could hold 190 pounds of MMH at a pH of 6.4.

Key accomplishments:

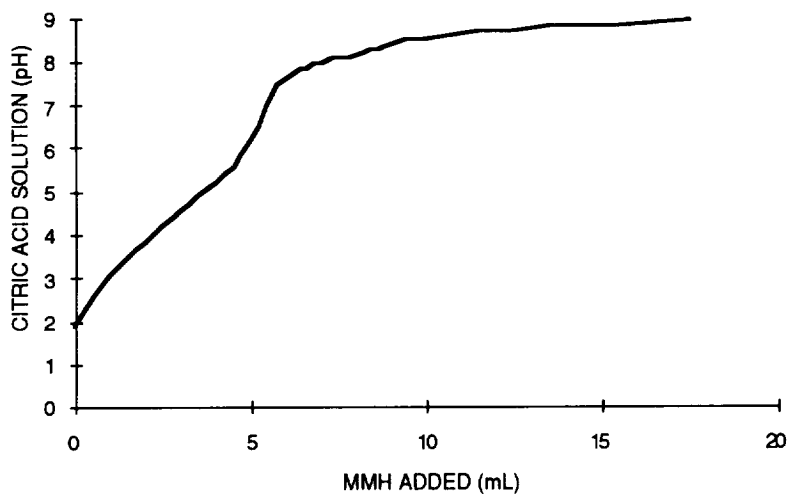
- The capacity of the 14-weight-percent citric acid solution is 3.35-weight-percent MMH at a pH of 6.4, which means a 650-gallon scrubber liquor tank can hold 190 pounds of MMH.
- Over 50-weight-percent decrease in MMH occurs in used scrubber liquor when the pH is increased from 2.88 to 7.0.
- The emission of MMH increases exponentially as the pH of used scrubber liquor is raised above 7, which means care should be exercised when neutralizing used citric acid scrubber liquors with sodium hydroxide to avoid MMH exposure.

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Participating Organization: I-NET Space Services (C.F. Parrish)



MMH Emissions During Neutralization With 5N Sodium Hydroxide



Potentiometric Titration of 14-Weight-Percent Citric Acid With MMH

Development of a Hydrazine Vapor Area Monitor (HVAM)

The American Conference of Government Industrial Hygienists (ACGIH) has proposed to lower the threshold limit values (TLV's) for all hydrazines [monomethylhydrazine (MMH), hydrazine (N_2H_4), and unsymmetrical dimethylhydrazine (UDMH)] to the 10-part-per-billion (ppb) level. An HVAM system has been developed and field tested that would provide long-term continuous monitoring of any area where hydrazine is stored or used at the proposed TLV to ensure worker safety.

The HVAM includes a purged cabinet containing power supplies, RS422/RS232 communications, an uninterruptable power supply, an onsite warning system, and the line replaceable unit (LRU). The LRU includes the analyzer, the liquid flow system with assorted flow and liquid-level sensors, and the control/data system microprocessor. The LRU is mounted on a track slide system so it can be serviced in place or quickly replaced with another calibrated unit, thus minimizing the analyzer downtime. The HVAM analyzer is an MDA/Polymetron Hydrazine Analyzer, which is a three-electrode liquid analyzer typically used in boiler feed water applications. The HVAM incorporates a dual-phase sample collection/transport system that simultaneously pulls air samples and a dilute sulfuric acid solution (0.0001 M) down a length of 1/4-inch-outside-diameter tubing from a remote site to the analyzer. The acid stream is separated from the air, and the pH is adjusted to greater than 10.2 prior to analysis by the addition of a dilute caustic solution. Both the dilute acid and caustic solutions are generated during system operation on an "as needed" basis by mixing a metered amount of concentrated acid/base with dilution water. The waste sample stream is purified for reuse by Barnstead ion-exchange cartridges so the system generates no waste materials. All liquids are pumped by a single pump motor fitted with an appropriate mix of peristaltic pump heads. The signal-to-noise ratio of the analyzer has been enhanced by adding a stirrer in the MDA liquid cell to provide mixing. An onboard VME computer continuously monitors liquid levels, the sample vacuum, and liquid leak sensors and handles communications and other system functions. The HVAM can be checked at regular intervals by measuring the analyzer response to a metered amount of calibration standard injected into the dilute acid stream pumped out to the sample point. The HVAM provides two detection ranges: (1) the TLV Mode for 2 to 1000 ppb and (2) the LEAK Mode for 20 ppb to 10 parts per million (ppm). The LEAK Mode range is created by diluting the liquid sample with pure water to keep it within the linear range of the sensor. Laboratory and field prototypes have demonstrated system response times on the order of 10 to 12 minutes in the TLV Mode and less than 2 minutes in the LEAK Mode. Service intervals of over 3 months have been demonstrated for continuous 24-hour-per-day, 7-day-per-week usage.

The HVAM prototype has been successfully field tested in the Titan IV Spacecraft Processing and Integration Facility (SPIF) (see the figure "Hydrazine Vapor Area Monitor in the SPIF") at Cape Canaveral Air Station from June through August 1994, and in the KSC Payload Hazardous Servicing Facility (PHSF) from September through October 1994. The information and experience gained through these two field tests will be used to refine and improve the HVAM design should the requirement to produce production units be realized after the ACGIH formally reduces the TLV to the 10-ppb level.

Key accomplishments:

- Buildup of the field prototype hydrazine analyzer system.
- 90-day laboratory testing of the field prototype hydrazine analyzer system.
- Qualification of the field prototype hydrazine analyzer system in the SPIF and PHSF areas.

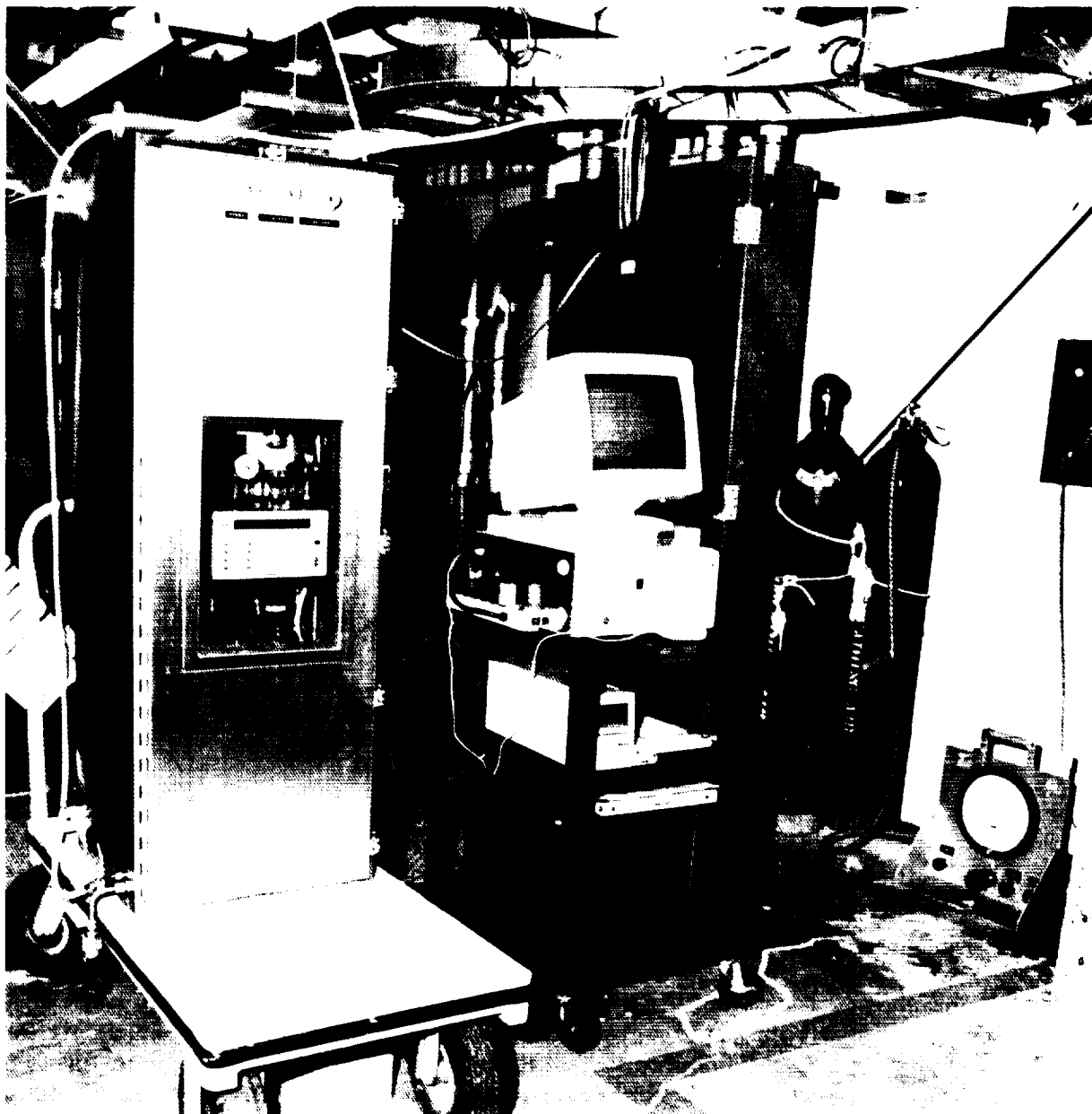


Key milestone:

- Continue to operate the prototype in the laboratory to gain further experience while waiting for ACGIH to formally adopt lower TLV's.

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Participating Organization: I-NET Space Services (B.J. Meneghelli)



Hydrazine Vapor Area Monitor in the SPIF

Portable Detector and Personal Dosimeter Technology Developments for Hydrazines (MMH, N₂H₄, and UDMH) at the 10-ppb Level

The American Conference of Governmental Industrial Hygienists (ACGIH) has proposed to lower the threshold limit values (TLV's) for all hydrazines to the 10-part-per-billion (ppb) level. In order to monitor the proposed TLV, work was done to develop portable detectors and personal dosimeters with detection thresholds below the 10-ppb level.

Phase II of a multiyear project to develop a battery-powered, portable hydrazine detector was completed this year. Previously, three technologies were investigated in the proof-of-concept phase for suitability of further development, with the Interscan electrochemical cell selected for advancement into the production prototype phase. Four production prototype units were tested in 1993 and 1994 and were found to meet the specified requirements. Based on the result of the Phase II tests, a technical specification was created that will form the basis for procurement of the production units when the ACGIH formally approves the lower TLV.

A conductive polymer-based hydrazine sensor (see the figure "Conductive Polymer-Based Hydrazine Sensor") was developed by Spectral Sciences, Inc., and Spire Corporation under a Small Business Innovation Research (SBIR) contract for the U.S. Air Force. The sensor showed the ability to detect hydrazine (N₂H₄) and unsymmetrical dimethylhydrazine (UDMH) below the proposed TLV of 10 ppb. Initial testing showed that films of the polymer poly(3-hexylthiophene) (P3HT), when doped with nitrosonium hexafluorophosphate (NOF₆), become conductive and are sensitive and specific for hydrazines. Films of the polymer/dopant material showed a significant and irreversible increase in resistance when exposed to constantly low (ppb) levels of dry hydrazine vapor. In order to characterize sensor response in more typical conditions, the NASA Toxic Vapor Detection Laboratory was tasked to test sensor response to nominal 10-ppb vapor streams of UDMH and N₂H₄ at a range of relative humidities from 0 to 60 percent. The test plan required sets of five sensors to be exposed to a constant nominal 10-ppb vapor concentration of N₂H₄ and UDMH (actual concentrations were 12.7 and 10.6 ppb, respectively) at specified relative humidities (0, 20, 40, and 60 percent). A data acquisition system provided resistance measurements during testing. The resistance increase of the polymer is proportional to the dose (product of concentration and time) by the following logarithmic function.

$$\ln(R/R_0) = k d$$

where d is the dose and k is a proportionality constant. During exposure to N₂H₄ and UDMH, the resistance of the sensors can increase from 1 k Ω to 100 M Ω . The sensor monitoring system was designed to precisely measure the resistance of the films over this wide range by applying a low current (0.1 μ A) to the sensors. Sensor sets were typically exposed to a minimum dose of 200 ppb-hr, although several sets were exposed until saturation was reached in order to determine a representative dynamic range.

The test results showed that humidities from 20 to 60 percent have a minimal effect on average sensor response to constant 10-ppb vapor concentrations of N₂H₄ and UDMH in air (see the figures "N₂H₄ Humidity Test Results" and "UDMH Humidity Test Results"). These sensors showed an easily measurable 10 percent change in resistance at 7 ppb-hr and a saturation dose of approximately 250 ppb-hr. The fact that the sensors had been in storage for over 1 year at the time these tests were performed speaks well for the stability of the polymer/dopant system. Repeatability between sensors is still a matter of concern, although several corrective measures might improve scatter (such as better control of film thickness deposited, concentration and distribution of dopant in the film, and electrode configuration).



Key accomplishments:

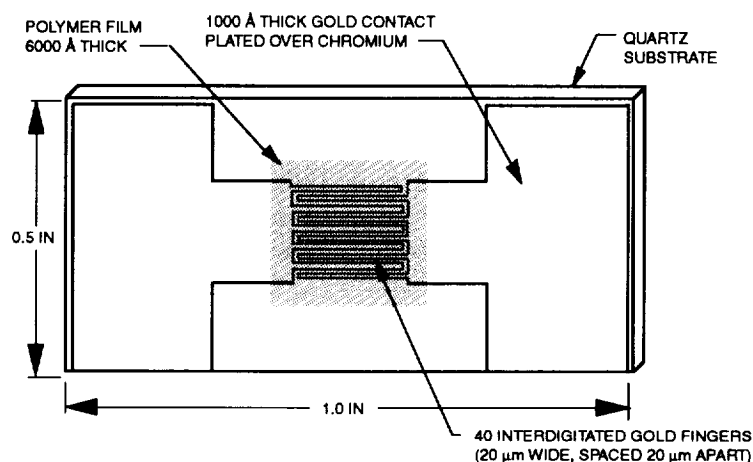
- Sensor evaluations completed.
- Results reported at the 1994 JANNAP Conference.
- Proposal submitted to the U.S. Air Force with recommendations to improve the sensor design.

Key milestone:

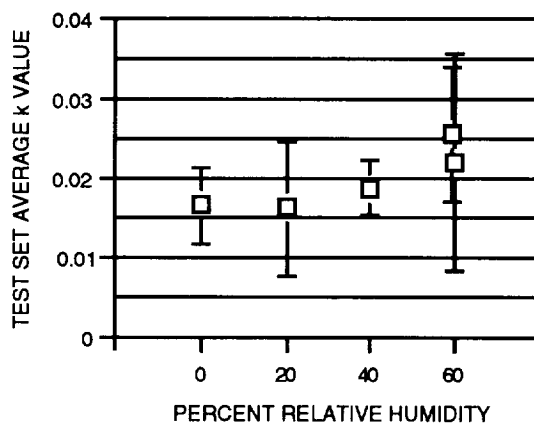
- Future testing will determine the applicability of the conductive polymer sensor for implementation as a personal dosimeter.

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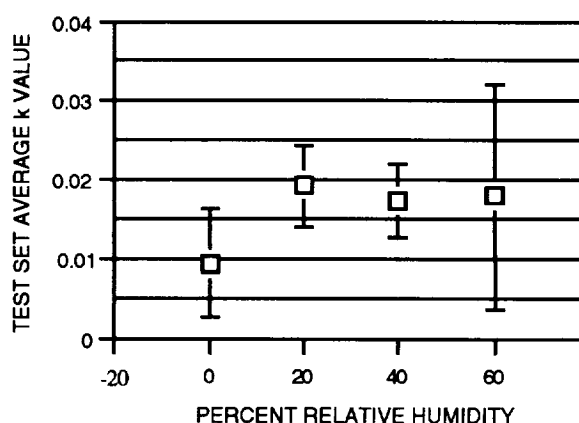
Participating Organization: I-NET Space Services (D.J. Curran)



Conductive Polymer-Based Hydrazine Sensor



N_2H_4 Humidity Test Results



UDMH Humidity Test Results

NOTE: ERROR BARS REPRESENT TWO STANDARD DEVIATIONS.

Chlorofluorocarbon (CFC) Replacement Precision Cleaning System Using Supersonic Nozzles

Recent links between chlorofluorocarbon 113 (CFC 113 or Freon) and upper atmospheric ozone depletion have caused KSC to plan the phaseout of all CFC's by 1995. CFC 113 is currently used in precision cleaning and cleanliness verification of small fittings, valves and regulators, large valves, pipes, flex hoses, and tubing. These parts come in contact with various fluids used by the Space Shuttle, especially liquid oxygen (LOX), which is the oxidizer used in the Space Shuttle Main Engines. Assurance of safe and troublefree flight performance led to the requirement that part surfaces be cleaned to a nonvolatile residue (NVR) level of 1 milligram per square foot of surface area, as well as a requirement of very low particulate residue (e.g., level 100, which specifies zero particles greater than 100 microns, 11 particles per square foot greater than 50 to 100 microns, etc.). The world scientific community has been actively engaged in finding replacements for CFC cleaning agents and solvents, but no clearly superior and acceptable candidates have been found.

A precision cleaning and verification system has been under development for several years at KSC. Small-parts NVR verification has been successful by submerging the parts in water and applying ultrasonic energy to remove NVR and particulates. The present task is to develop a precision cleaning system to replace CFC 113 for cleaning and verifying large parts such as 6-inch stainless-steel valves used in LOX service. The new system applies an air and water mixture accelerated in a supersonic nozzle that removes contamination by impingement. Breathing air and deionized water are the fluids of choice because they are practically free of contaminants that could confound the cleaning and verification process. The breathing air/water (BAir/Water) system (see the figure "Gas-Liquid Supersonic Nozzle System") consists of a regulated air supply, a pressurized water tank, a flex hose, the nozzle assembly, and the associated valves, fittings, and hardware. Air pressure forces the water into the air stream and into the nozzle where the air/water mixture is accelerated to a design Mach number of 3.2. Water, which drains off the valve, is captured and assayed for total carbon in terms of parts per million (ppm) of carbon in the water sample.

A series of tests with known contamination on witness plates has resulted in linear relationships between total organic carbon (TOC) and the initial contaminant level (see the figure "Initial Contaminant Level") and the TOC NVR removed (see the figure "NVR Removed"). The impingement tests were verified by performing the existing CFC 113 gravimetric procedure as an experimental control. These figures are typical of the four contaminants in this study, which are routinely found in piping and tubing hardware. The results show there will likely be a correlation between the existing gravimetric NVR method using CFC 113 and the BAir/Water impingement method of cleaning verification.

Key accomplishments:

- A new supersonic impingement system was fabricated and tested.
- Results show that BAir/Water impingement is a feasible replacement method for CFC 113 cleaning verification.

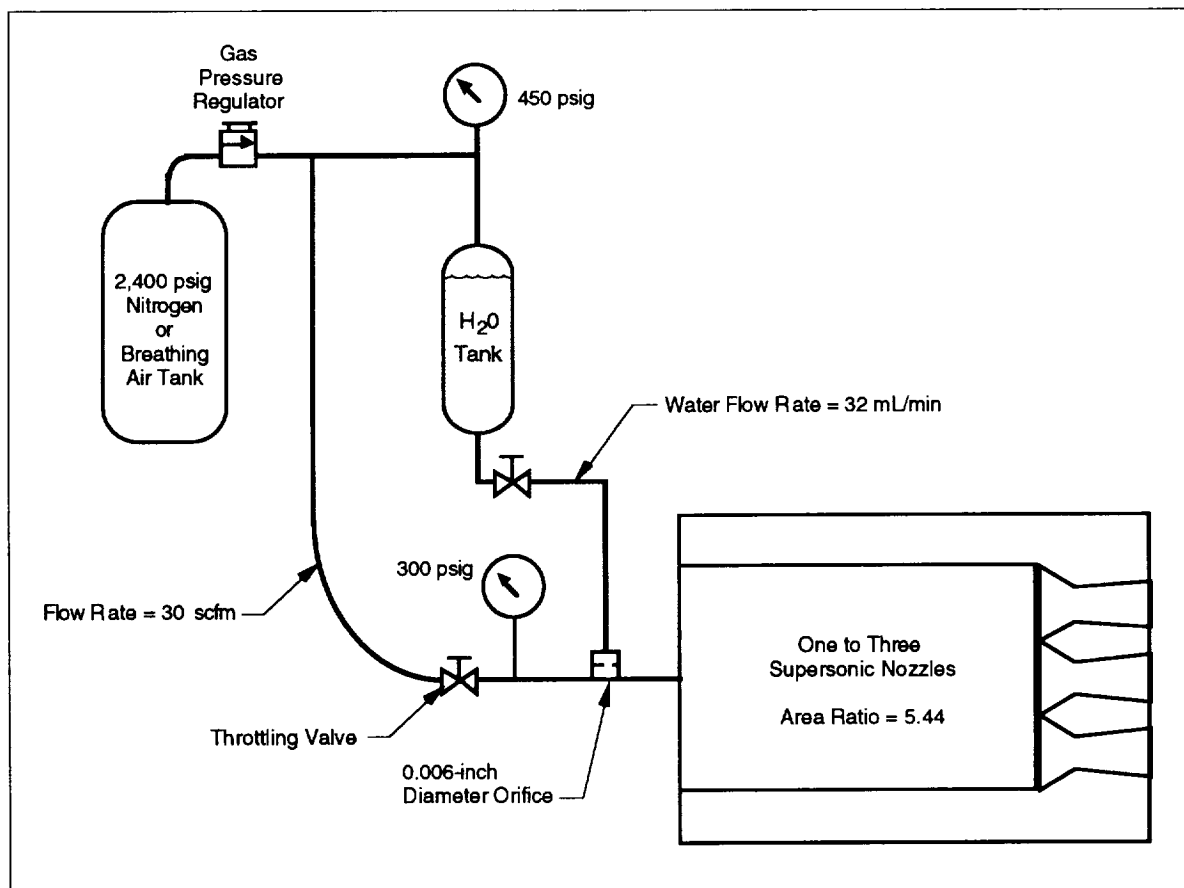
Key milestones:

- Test the actual valves and other hardware.
- Develop a correlation between CFC gravimetric NVR and the BAir/Water impingement verification system.

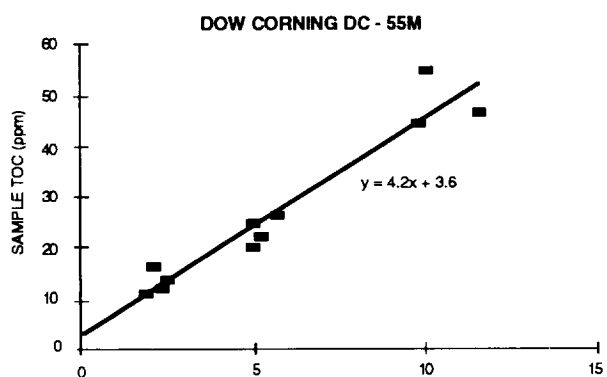


Contacts: G.S. Melton, DM-MSL-2M; E.A. Thaxton, DM-ASD; and R.E. Caimi, DM-ASD,
(407) 867-7048

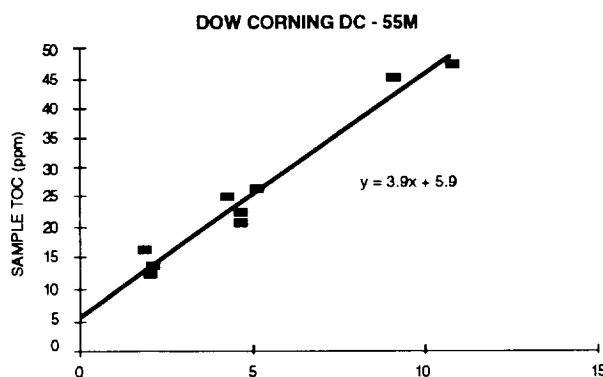
Participating Organization: I-NET Space Services (C.K. Cantrell, C.H. Fogarty, and R.G. Barile)



Gas-Liquid Supersonic Nozzle System



Initial Containment Level (mg)



NVR Removed (mg)

Mapping Analysis and Planning Systems

At KSC (as at other large Federal facilities), the management, analyses, and interpretation of extensive and diverse volumes of environmental data are required to operate the facility in compliance with local, state, and Federal laws and regulations. Users of the data include the Environmental Management Office, Master Planning Office, Pollution Control Office, U.S. Fish and Wildlife Service, National Park Service, U.S. Air Force, and various other KSC, state, and local organizations.

An increasing demand exists for local maps and charts of geographic-type environmental data (e.g., vegetation types, location of habitat for threatened and endangered species, and location of wetlands) to support environmental decisionmaking in the operation of KSC. The objective of the Mapping Analysis and Planning Systems (MAPS) project is to develop a network of integrated workstation-type computer systems that link a knowledge-based computer shell to centralized Geographic Information System (GIS) databases, environmental models, and other environmental data to enhance and streamline the environmental management decisionmaking process.

The initial workstation establishment has increased the output of useful information to various users; concomitantly, the information requests have increased. Further development of the system, including expanded networks, knowledge-base integration, neural networks, and more powerful hardware, will ensure the capability to support the data users.

Key accomplishments:

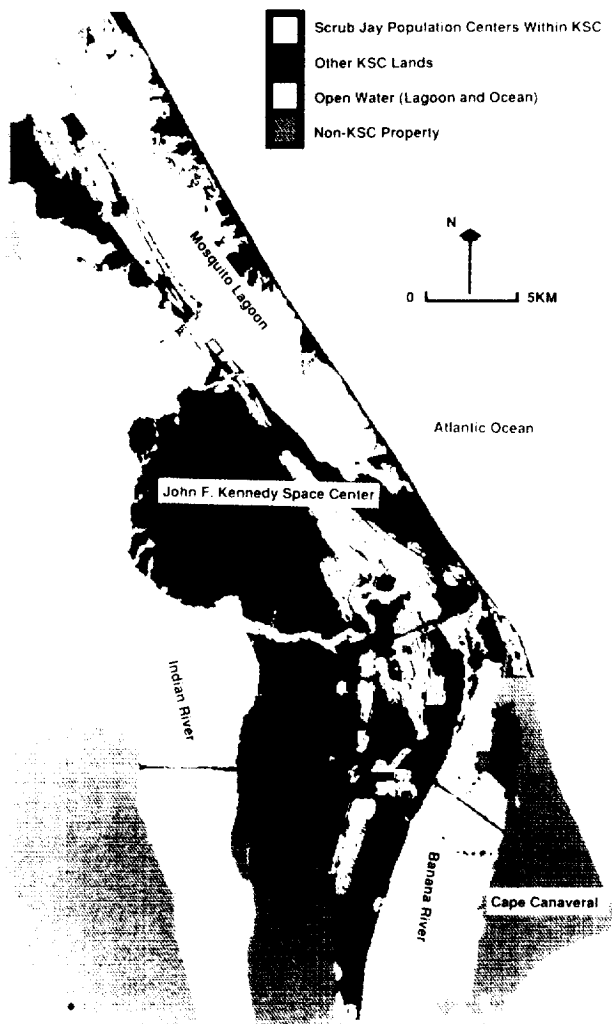
- 1990: Initial system setup was accomplished, and a pilot study was completed.
- 1991: Hardware and software were obtained and configured, and existing data were placed into the system.
- 1992: A Local Area Network (LAN) was established for user access, and a global positioning system was acquired to streamline input of geographic data.
- 1993: The global positioning system was incorporated into daily field activities such as identification of permanent sampling locations. A knowledge-based system was compiled that incorporated as-sorted environmental data to assist in environmental impact documentation. Three-dimensional modeling of ground water contamination sites utilizing masterplanning files, SPOT data, and tabular data were accomplished. A Visiting Investigator Program (VIP) was initiated with Stennis Space Flight Center and the University of South Carolina.
- 1994: Established a microwave link to allow for rapid data transmission. Distributed environmental information to other users through Mosaic. Incorporated a major relational database management system. Completed the VIP with Stennis Space Flight Center.

Key milestones:

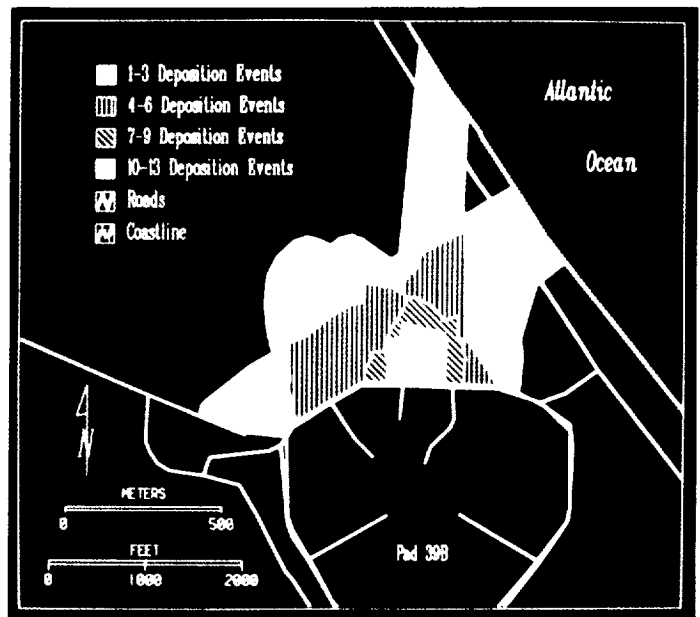
- 1994: Establish a decision support system in DE-EMO. Incorporate additional information analysis modules. Develop a meta database for system documentation. Continue the development of a distributed database.

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Participating Organization: The Bionetics Corporation (M.J. Provancha)



Geographic Information System Map of Potential Scrub Jay Habitat at KSC



Documentation of Near-Field Launch Effects Using GIS Technology



Geographic Information System Workstation



LANDSAT Image of KSC for Use in Resource Management



The Electronics and Instrumentation Technology program at the John F. Kennedy Space Center (KSC) supports the development of advanced electronic engineering technologies that decrease vehicle and payload ground processing time and cost, improve process automation, and enhance quality and safety. The program includes the application of electrical and electronic engineering disciplines, particularly in the areas of data acquisition and transmission, advanced audio systems, digital computer-controlled video, environmental monitoring instruments, and circuit monitoring instrumentation. The near-term program focuses on Shuttle ground processing enhancement by developing instruments that improve ground support equipment used in monitoring and testing. The long-term program will develop technology for support of future space vehicles, payloads, and launch systems by investigating instruments that can provide "component intelligence" and contribute to vehicle health management data for synergy with the Advanced Software systems under development.

Electronics and Instrumentation

T-0 Cable Analysis System

Currently, the checkout of the cables at the T-0 cable plant for the Space Shuttle at KSC is done by time-consuming manual methods. A test set must be manually plugged in at either end of a cable. If an anomaly is detected, one test set is moved along various junctions of the cable until it is located. The ends of the cable are separated by a large distance, thus further slowing the testing.

The objective of the T-0 Cable Analysis System (CAS) project is to develop an advanced cable analysis system for the T-0 cable plant from the Pad Terminal Connection Room (PTCR) to the orbiter and from the PTCR to the Payload Changeout Room (PCR). The system will include intelligent remote terminators, historical archiving of test results, fault prediction, and report-generation capabilities. The goal of the program is to test cables in place through the use of intelligent remote configurators. These configurators attach to the end of the cable under test, receive the data from a suitcase-based tester through the cable under test, and reconfigure based on that data. This is a joint project between NASA, Lockheed Space Operations Company, and Lockheed Sanders.

Initial field testing of the prototype unit was successfully completed. The testing was performed at Launch Complex 39, Pad A, on 25 circuits (16 AWG) running 800 feet. CAS can perform resistance tests and low-voltage isolation tests.

Key accomplishments:

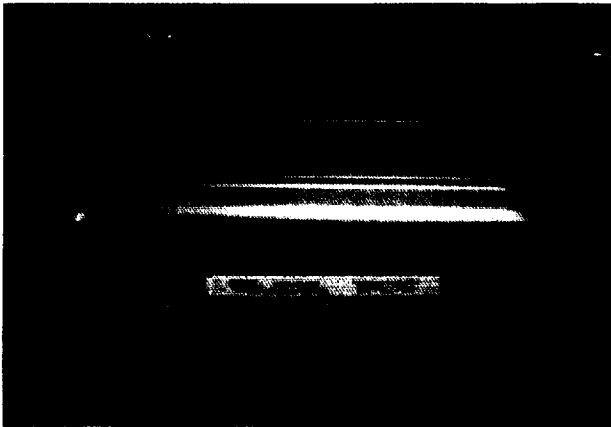
- 1992: Prototype breadboard assembled.
- 1993: Completion of a new high-speed current source. Completion of a track and hold circuit.
- 1994: Delivery of the prototype test unit to KSC. Completion of initial field testing.

Key milestone:

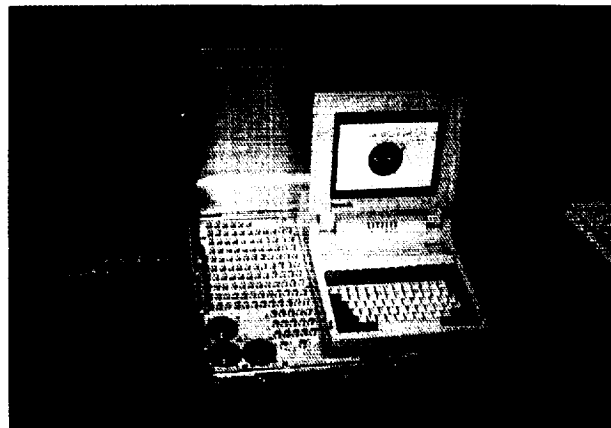
- 1994: Commence final field testing of the prototype test unit.

Contact: D.C. Knoblock, TV-ETD-5, (407) 861-3690

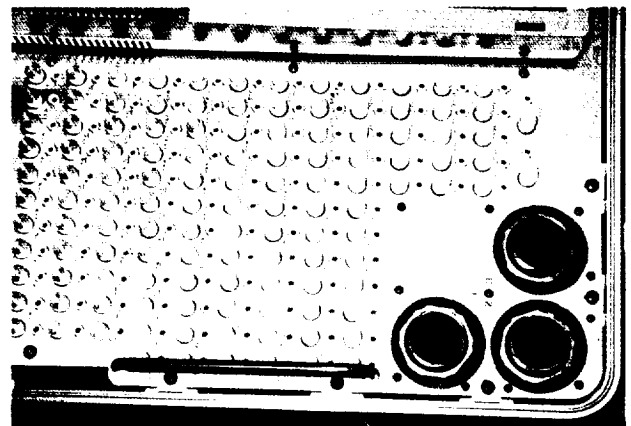
Participating Organizations: Lockheed Space Operations Company (L.T. Bird) and Lockheed Sanders (B. Houvener)



T-0 Cable Analysis Prototype



View Showing Case Open



Closeup of Connectors and Switches

Propagation of Oxygen-Deficient Conditions When Nitrogen and Helium Are Released

Large quantities of nitrogen and helium are used during launch vehicle and payload processing at KSC. The possibility for exposure of personnel to oxygen-deficient atmospheres is guarded against by the installation of an Oxygen Deficiency Monitoring System (ODMS). The goal of a properly designed oxygen monitoring system is to select the number and location of sampling points to provide adequate coverage in each monitored area, while minimizing the number of oxygen analyzers in the system. In order to do this, the designer must understand how nitrogen and helium propagate from the point of release.

Studies were performed at KSC involving the release of gaseous nitrogen and helium at various flow rates and under differing conditions. These tests involved releasing gases into small and large ventilated and unventilated spaces. The leaks also represented both point leak sources as well as diffuse leak sources. The oxygen concentration in the vicinity of the leak was then monitored with oxygen analyzers. The data depicted in the figure shows a "snapshot" of the oxygen concentration at a specific time during the release of nitrogen. The area shown by the contour map is actually a hallway with a doorway leading into a side room. The walls and dividers of the room and hall are shown in black lines overlaid on the contour map. The oxygen concentration data were collected on a second-by-second basis, and the resulting contour map shows the evolution of the oxygen deficiency over time and space. This type of detailed information is expected to aid the ODMS designers in their task.

This project was initiated and completed during fiscal year 1994.

Key accomplishments:

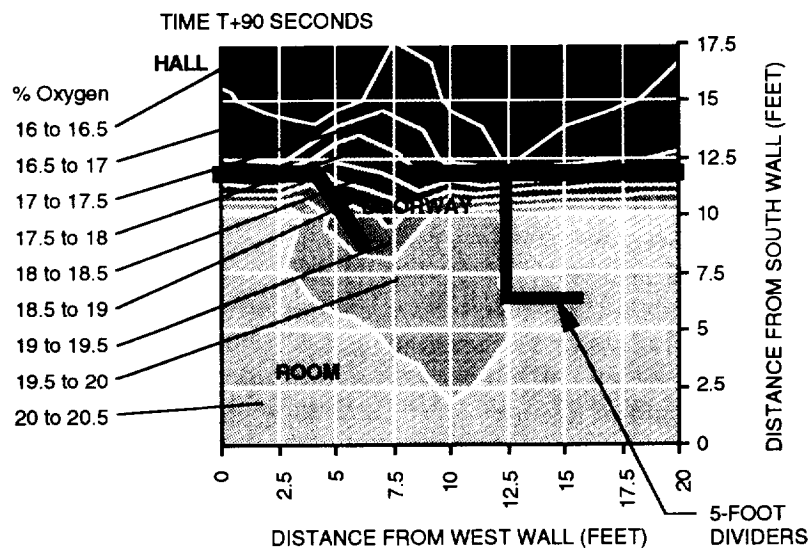
- Determined scenarios to be tested and developed test procedures.
- Assembly of hardware and testing.
- Preparation of final report.

Contact: P.A. Mogan, DL-ICD-A, (407) 867-9167

Participating Organizations: I-NET Space Services (C.J. Schwindt and T.R. Hodge) and McDonnell Douglas Space and Defense Systems (V. Bukauskas and L.H. Allen)



Test 2A: 900-cubic-foot volume of nitrogen at 500 cubic feet per minute in the hall



*Map of Oxygen Concentration at Breathing Level (5 Feet),
90 Seconds After Start of Simulated Leak in Hall*

Low-Cost, Remote Control, Real-Time Data Acquisition System To Acquire and Monitor Launch-Critical Environmental Measurements

During a Shuttle launch, ground support equipment and structures in the proximity of the launch pad are subjected to intense (greater than 180 decibels) acoustic pressures generated by rocket exhausts. Past research at KSC has focused on techniques to characterize noise and predict vibroacoustic behavior. Simply stated, vibroacoustics or vibroacoustic coupling is a measure of a structure's affinity to vibrate when subjected to acoustic loads, leading to degradation of structures and thereby increasing maintenance costs. Thus, continuous monitoring of launch-critical loads (acoustics) and simultaneous structural response (vibration and strain) are vital for maintaining KSC's leadership role in preparing and launching Shuttle missions and for ensuring operational safety and long-term reliability of critical launch pad structures.

To accomplish the above, a low-cost, remotely controllable, real-time data acquisition system (DAS) has been developed and is in operation on Launch Pad 39A at KSC. This effort is part of a multiyear test validation project titled Verification Test Article (VETA). The DAS includes two TEAC digital audio tape (DAT) recorders, controlled by a pad computer using TEAC QuikVu software. The pad computer and DAT recorders in turn are networked (via KSDN) and controlled remotely by an office computer located in the KSC Headquarters Building using the pcAnywhere software. With the DAS, launch data can be sampled at 48,000 samples per second, with a recording and reproduction frequency of direct current to 20 kilohertz and a data resolution of 14 bits. The DAS is capable of simultaneously monitoring and acquiring 16 channels of data at a cost per channel of less than \$3K. Lastly, launch data can be transferred immediately to the NASA VAX platform via the Ethernet network for use by NASA engineers for further analysis.

Key accomplishments:

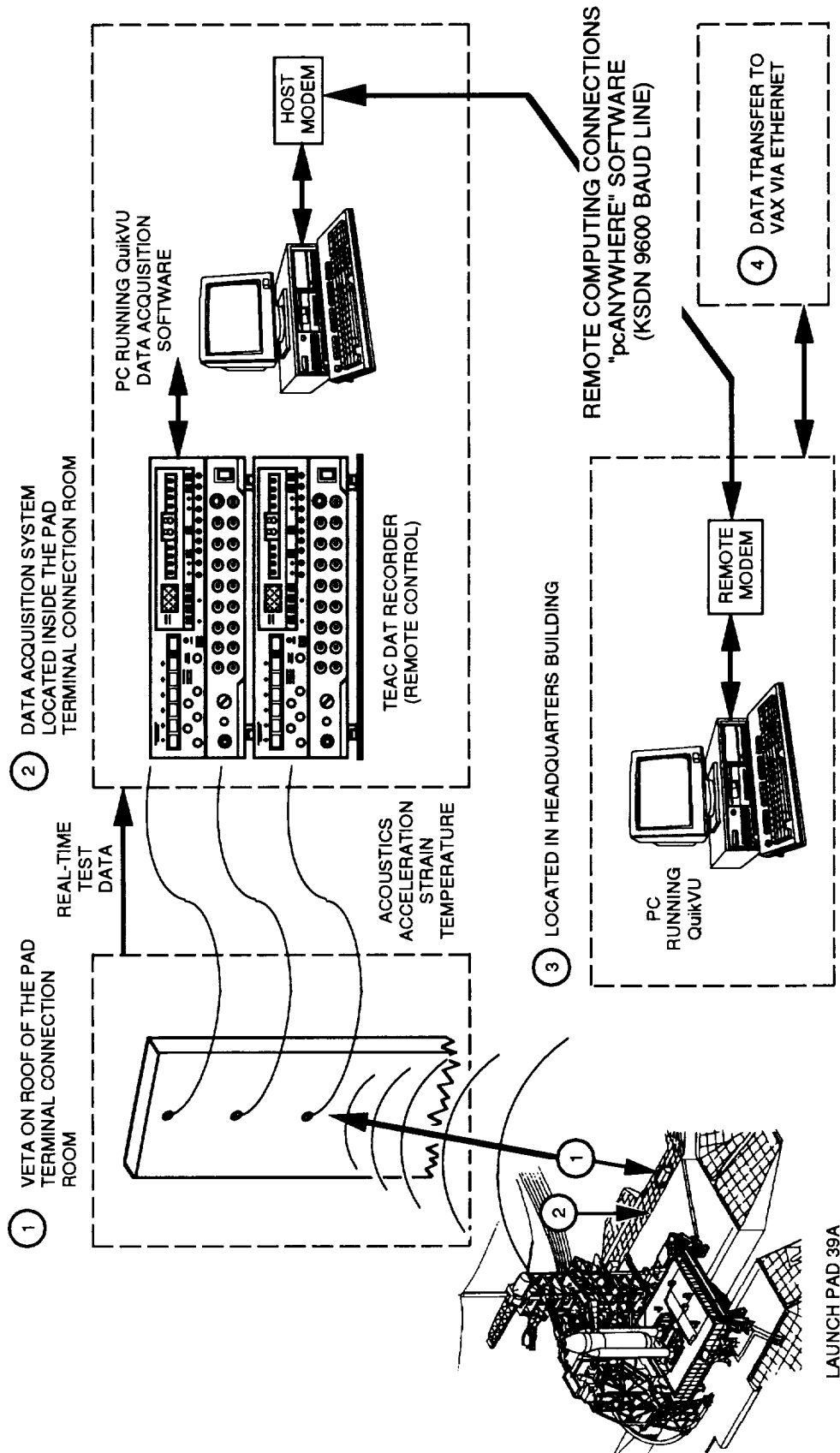
- The DAS performed flawlessly during STS-59, -65, -68, -64, and -66 launches; provided instant data monitoring and accessibility; was suitable for both near-field and far-field work; can be extended to remote locations wherever KSDN exists; and is suitable for acquiring data from Titan and Delta launches.

Key milestone:

- 1995: Acquire launch data for five launches from Launch Pad A.

Contact: R.E. Caimi, DM-ASD, (407) 867-4181

Participating Organization: I-NET Space Services (R.N. Margasahayam)



*Verification Test Article (VETA) Program
Real-Time Data Acquisition and Monitoring of Shuttle
Launch Acoustics and Structural Vibration Data*

CCD-Based Real-Time Particle Fallout Monitor Development

Space flight hardware is sensitive to particulate fallout contamination during most phases of ground operations and processing. Present methods for monitoring fallout contamination at KSC are based on a 2-week accumulated count at fixed locations around a space flight hardware processing facility and, therefore, do not allow potentially destructive contamination events to be detected until after the fact. Risk of payload damage from undetected contamination events is consequently a very real possibility. A small, automated, real-time particle fallout monitor capable of counting and sizing particulate fallout (allowing a facility's cleanliness classification to be continuously monitored) has become a developmental goal.

The task was to develop a breadboard laboratory device, which would demonstrate the imaging, sizing, and counting of particulate fallout, in a configuration with the potential for further development into a real-time, self-contained instrument. A charge-coupled device (CCD) was selected along with a unique illumination scheme and some powerful commercial image analysis software to give a high-contrast particulate imaging capability that targets the 10-micrometer-size range and up.

In 1994, a bench-top device was constructed that performed the required job. An illumination scheme that depends on edge-lighting and internal reflections in glass gave a high-contrast image, which is important for the image analysis software to do its job properly. The CCD device was integrated into the image analysis system. Work was initiated on identification and programming of microcontrollers and microprocessors, the intent being to identify a suitable platform that will constitute the brain of the new instrument.

1994 accomplishments:

- Illumination scheme was identified, designed, and fabricated.
- CCD camera and its associated optics was identified, procured, and configured.
- Bench-top device was integrated with a commercial image analysis system.

1995 milestones:

- Fallout statistics computer model to be developed.
- Improved demonstration device to be designed and fabricated.
- Image analysis software critical modules to be extracted and put into a smaller computer that fits into the instrument.

Contact: P.A. Mogan, DL-ICD-A, (407) 867-9167

Participating Organizations: I-NET Space Services (C.J. Schwindt, J. Sentz, R.C. Youngquist, J.S. Moerk, and K. Rose) and McDonnell Douglas Aerospace Space Systems (V. Bukauskas and L.H. Allen)



**Versatile Fourier Transform Infrared (FTIR)
Spectrometer-Based Vapor Detection System for Use in KSC Facilities**

Facilities at KSC process a large variety of spacecraft. During processing, different substances are used, including hypergolic fuels, waterproofing compounds, refrigerants, solvents, and lubricants. A diversity of instrumentation, using several different technologies and having widely varying operating and maintenance requirements, is currently used to detect and monitor these substances. During the past few years, an FTIR-based detection system was developed for replacement of the current Hypergolic Vapor Detection System at Launch Complex 34. In fiscal year 1994, the system was advanced to the point it can be readily applied to many vapor detection tasks in processing facilities and in laboratories.

Currently, the FTIR module has been applied successfully in KSC facilities for detection of dimethylethoxysilane (DMES, the Orbiter tile rewaterproofing compound) and tetramethyldisiloxane (a byproduct). The same module has also been demonstrated in the laboratory for detection of hypergols, ammonia vapor, and solvents. It has been selected as the basis for the ammonia monitoring system in the Space Station Processing Facility and has been proposed as a solvent vapor monitor for use in the new Cleaning, Refurbishment, and Chemical Analysis Facility. Consideration is also being given for its use as a total hydrocarbon monitor for KSC processing facilities.

Key accomplishments:

- Demonstration of a high degree of flexibility and ease of use.
- Development of a fieldable cart instrument capable of stand-alone, unattended operation.
- Training of the FTIR to recognize spectra of many new compounds.
- Fielding of the prototype unit in the Orbiter Processing Facility for use as a DMES monitor.

Key milestones:

- Fielding of the final DMES monitor cart.
- Field demonstration as a total hydrocarbon monitor.
- Field demonstration as a solvent vapor monitor.

Contact: P.A. Mogan, DL-ICD-A, (407) 867-9167

Participating Organization: I-NET Space Services (C.J. Schwindt and C.B. Mattson)



The goal of the Advanced Software Technology program at the John F. Kennedy Space Center (KSC) is to investigate emerging computer technologies to meet current mission requirements and to ensure leading-edge technologies will be available to fulfill future vehicle, payload, and launch requirements.

To meet the challenge to become more effective in all aspects of KSC work, reliability and safety must be maintained as processing time and cost are reduced. Never has a mandate been clearer nor an opportunity more timely. Products must be extracted from the expanding technological base, and these products must be utilized to solve KSC's needs.

This year's advanced software programs employ a broad range of disciplines and technologies. Programs include a notable emphasis on artificially intelligent systems. The Ground Processing Scheduling System provides an artificial-intelligence-based scheduling tool. An automated database design tool utilizes a rule-based system and two knowledge sources. KATE-PC makes available model-based reasoning technology to inexpensive PC platforms. EXODUS provides a common set of utilities for independent advisory systems. PAT utilizes a rule/model base to monitor propulsion system health. The VHMS tool reduces labor required for orbiter powerup by working with a knowledge-based system called KATE.

Progress was also made in conventional software areas. These include a graphical storage and plot system that allows office workstation access to Shuttle data, a wireless information network (WIN) that links laptops to a remote host, and an innovative venture between NASA, universities, and private individuals to allow inexpensive platforms to communicate on Usenet. Last, but not least, is the development of a small virtual reality system being explored for possible use at KSC.

Advanced Software

Advanced Shuttle Scheduling Technologies — Ground Processing Scheduling Systems (GPSS)

The GPSS is an artificial-intelligence-based scheduling tool being developed to support the complexity and dynamics associated with the scheduling of Space Shuttle ground processing at KSC. The focus of the GPSS development has been to support the processing activity in the Orbiter Processing Facility (OPF). Scheduling in the OPF demands the integration of the processing requirements for 24 major orbiter systems with (1) a majority of the processing worked in parallel; (2) temporal, configuration, and resource constraints associated with each system's supporting tasks; (3) frequent rescheduling in response to unexpected events; and (4) the need for timely communication of schedule information. The GPSS must also be capable of successfully integrating with the Shuttle Operations Integrated Work Control System (IWCS). The IWCS contains four key components; one of the components is based on requirements to improve current (predominately manual) scheduling processes.

In order to meet the Shuttle processing scheduling challenge, the GPSS development team has successfully utilized NASA intercenter expertise and a rapid development approach with dedicated user support. The GPSS constraint-based algorithms have been developed to model the temporal, configuration, and resource constraints of each activity; perform schedule conflict resolution; and respond with schedules containing minimal constraint violations. The user interface has been developed with advanced interactive capabilities that allow the users to effectively manipulate the schedule model and provide the necessary output for decision support.

The GPSS activity supports the NASA research and technology development goals for technology transfer. The development software has been coded in LISP and C. In return for a license agreement to develop and market the first commercial version of the software, an independent software company will provide NASA KSC with its version of the software coded in C++. This commercial version will provide Shuttle Operations with a fully operational and sustainable tool and will support integration with the IWCS. Future plans include operational deployment and full integration with the IWCS, development and implementation of the supporting business processes, development and implementation of multiframe/multisite deconfliction capabilities, and development and implementation of a performance measurement system that supports the evaluation of the impact of scheduling technology improvements on operations.

Key accomplishments:

- 1989: First introduction of the GPSS project to KSC.
- 1990: Prototype system to support OPF processing ready for testing.
- 1991: Initial OPF knowledge base established via field testing.
- 1992: OPF schedules produced for Space Shuttles Columbia and Endeavour via operational testing.
- 1993: Schedule compression and conflict resolution capabilities incorporated within the test bed system. Scheduling activity supported for all OPF processing. GPSS team received the Space Act Award. GPSS software licensed for commercial development.

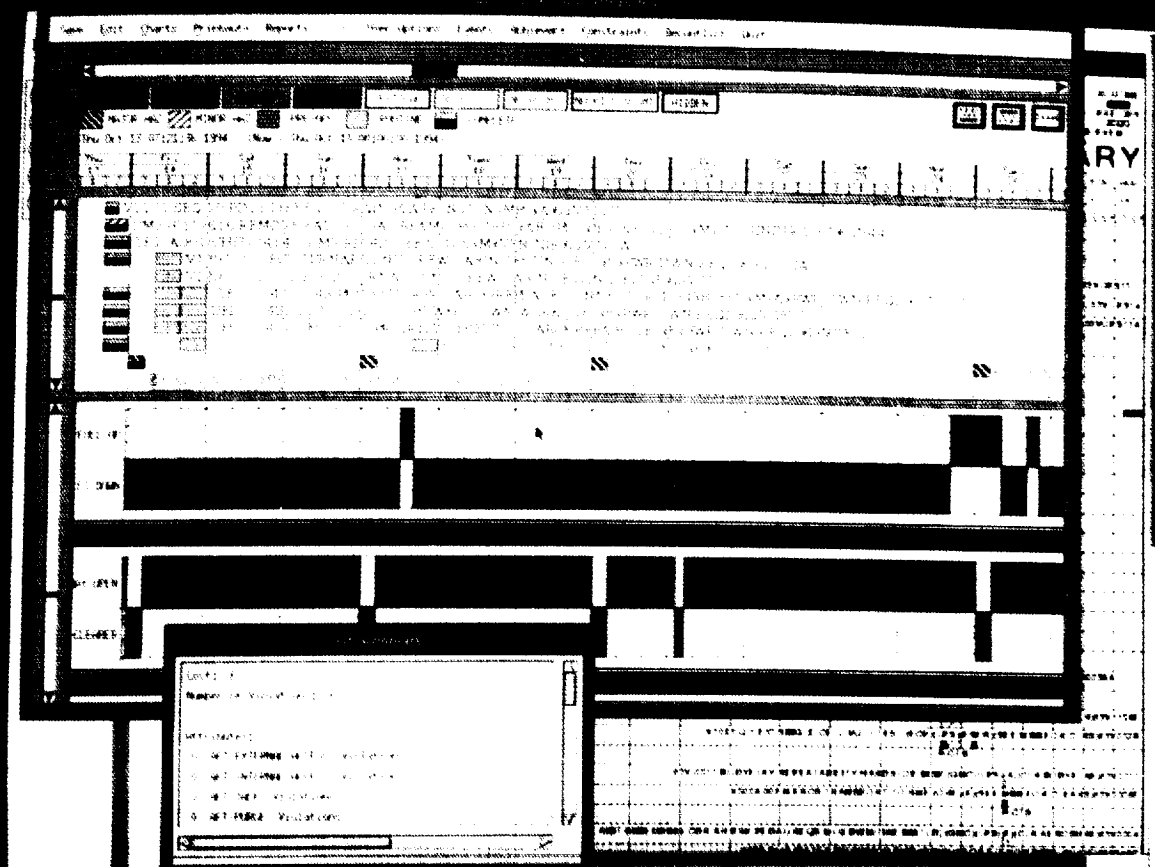
Key milestones:

- 1994: Validation, acceptance, and implementation of the first operational and sustainable version of the GPSS.
- 1995: Implementation of the GPSS as a fully functional application within the Shuttle Operations IWCS. Implementation of the scheduling technology performance measurement system.



Contact: N. Passonno, TP-PED-2, (407) 861-5428

Participating Organizations: Lockheed Space Operations Company (D.L. Kautz) and NASA Ames Research Center (P. Friedland)



GPSS - Typical Working Screen Layout:

- KICS Schedule (in background)
- Task/Resource Histogram Window
- Conflict Summary Window
(top level information on schedule conflicts)

KATE-PC: Diagnostic Software in a Desktop Environment

KATE is a model-based monitoring and diagnostic system developed to support Shuttle launch processing operations. KATE was designed to be a "generic" software system, meaning that KATE can perform monitoring and diagnosis of any physical system that can be mathematically modeled. This lends itself to potential use by a wide class of users. The objective is to make the KATE software widely available to NASA and all of industry for application use and for further development. However, there are two problems that prevent model-based reasoning (MBR) technology (and, therefore, KATE) from being utilized on a widespread basis.

The first problem is that KATE is currently available in Common LISP (on a Symbolics LISP machine platform) and in C++ (on a Sun SPARC UNIX platform). This prevents organizations without expensive LISP or UNIX platforms from utilizing the KATE model-based reasoning technology. The second problem prohibiting the widespread use of MBR technology and KATE is the difficulty of the model-building process. It is difficult for an engineer who is unfamiliar with KATE knowledge base (KB) syntax to create a mathematical model of a system. Several end-users have asked for a model-building tool with a graphical user interface instead of the purely textual interface that currently exists.

Realizing these two problems combine to prevent MBR's widespread use, decisions were made to begin porting several modules of the KATE software to a personal computer (PC) environment and to pursue the development of a graphical model builder.

First, the reasoner and KB modules of the KATE software have been ported from the UNIX workstation environment to a PC, retaining as much of the original functionality as possible. Specifically, the PC version was developed and compiled in Borland C++, running under Windows 3.1. The extreme popularity of Windows will make KATE available to a larger percentage of Government and industry. Retaining the same base language (C++) allows the porting of large portions of the software to the PC "as is," needing only recompilation. However, there are several modules, especially the user interface and interprocess communication, that must be redesigned for the PC environment.

Secondly, a graphical user interface is being developed as a front end to the model-building process. The first phase of the migration to a graphical interface will consist of the development of a flatfile editor called Graphical FlatFile Editor (GFFE). GFFE is being developed in cooperation with the Florida Institute of Technology. GFFE is a model-building editor that allows a user to graphically choose components from an icon library and to drag them over to the model window and "connect" them with other components. The user then "specializes" each component's parameters (such as name, nomenclature, voltage, admittance, etc.) making it a unique instance. The collection of these connected instances constitutes a model. In the future, models will be segmentable into files or pages for manageability. GFFE is written in C++, X windows, and the Motif windows manager and runs on Sun SPARCstations, requiring SunOS 4.1.X, X11R5, and Motif 1.2.

The KATE-C reasoner and KB modules have been ported to a PC running Windows 3.1 (KATE-PC). The first-phase system will have the capability to run model simulations when completed. In the future, the data provider, fault detector, and diagnoser modules can be ported, providing full monitoring functionality.



The GFFE first phase has been developed and demonstrated. Currently the user is able to select new components and place them into a model "page." Components can then be connected together by a click-and-drag with the mouse. Once a model is created, the user can "generate" a KATE-readable flatfile by a click with the mouse. This flatfile is then loaded into KATE for testing or monitoring.

Key accomplishments:

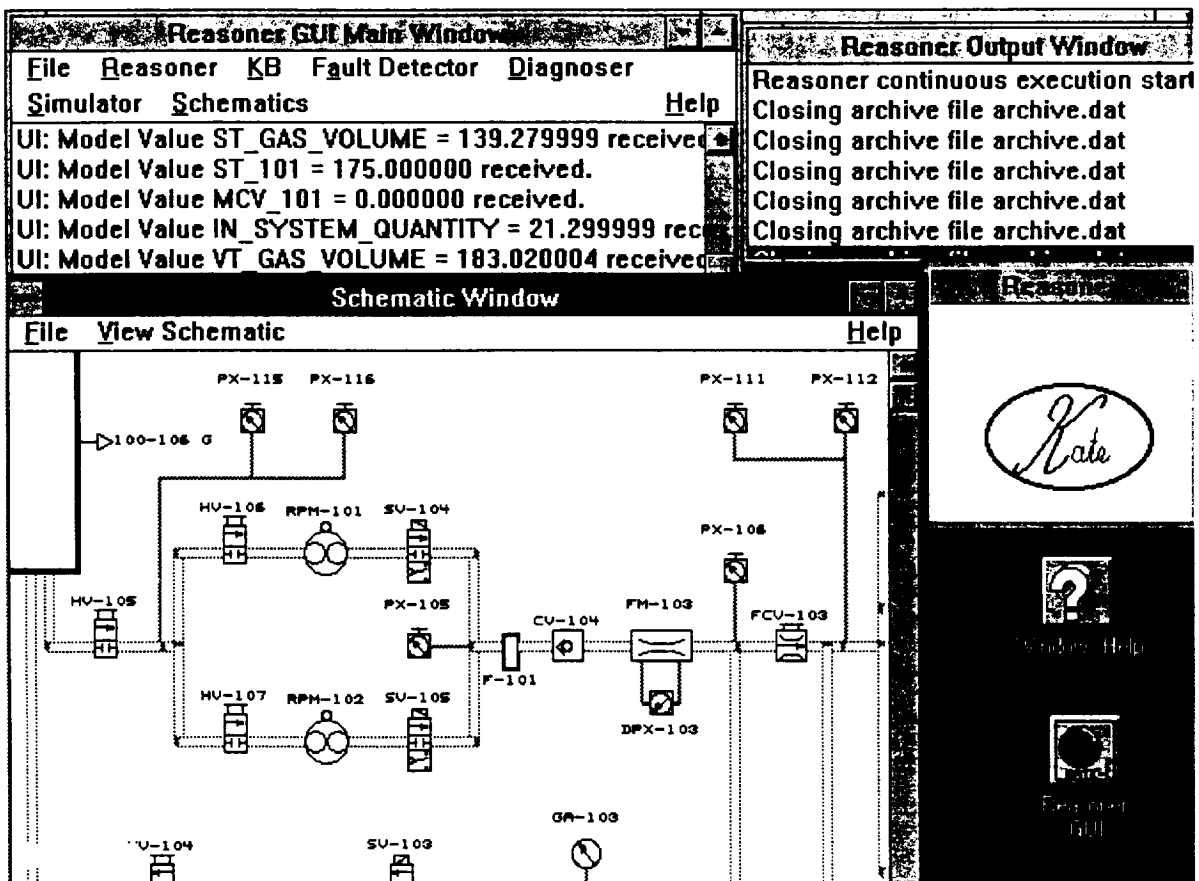
- Implemented the KATE-C reasoner and KB modules on a PC platform.
- Successfully demonstrated a KATE model simulation on the PC.
- Completed the first phase of the graphical flatfile editor.

Key milestones:

- Complete the reimplementaion of KATE-C on a PC.
- Continue the development of the graphical editor, with the goal of demonstrating the creation and maintenance of a working model.

Contacts: B.L. Brown, DM-ASD, (407) 867-4156, and C.L. Parrish, DM-ASD, (407) 867-4181

Participating Organizations: I-NET Space Services (C.H. Goodrich) and Florida Institute of Technology (Dr. D. Tamir)



Expert Systems for Operations Distributed Users (EXODUS)

In an effort to improve monitoring and analysis of Shuttle processing and launch operations at KSC, advisory systems are under development to augment the current capabilities of the Checkout, Control, and Monitoring Subsystem (CCMS). The CCMS is composed primarily of a MODCOMP distributed computer system located in control rooms at KSC and dedicated to Shuttle, payload, and hypergolic systems processing. Memory and central processing unit requirements prevent the advisory systems from executing on the CCMS, but they must have access to vehicle and ground data stored in the CCMS. A port from the common data buffer provides this data in raw format over the Launch Processing System operations network (LON) Ethernet. The advisory systems must acquire this data to alert system engineers of anomalous conditions and to recommend courses of action. Reference documentation is also provided by the advisory systems to assist engineers in the understanding of an anomalous condition. Development of these advisory systems by various engineering organizations has led to the implementation of independent systems that must address some of the same basic requirements. The cost to KSC to develop and maintain these independent systems in areas of re-engineering is high and increases as new advisory systems are developed. If there were a set of common utilities that perform the basic functions all advisory systems require, a substantial savings in development costs and time could be achieved while providing some standardization.

The goals and objectives for EXODUS are to provide a set of utilities for advisory systems that will allow data acquisition, conversion, and storage and to provide a database server and database interface utilities that accesses vehicle-related documentation and information. Developers of advisory systems can then focus manpower and budget on solving specific applications. Data acquisition, conversion, and storage are provided through an EXODUS function called UNIX Checkout and Monitoring Subsystem (UCMS). The UCMS reads the raw data packets of vehicle and ground measurements from the LON and converts the data to function designators and engineering units so applications are insulated from changes in data transmission from flight to flight. The UCMS can support from one to four control data sources simultaneously. The UCMS also provides utility functions for reading measurement data, data recording, data retrieval, and data monitoring. The database server is a UNIX workstation that contains various documents and information related to Shuttle processing and testing. A database interface utility is provided to allow advisory systems to read and display data requested from the server.

A functional prototype of EXODUS has been released. Current EXODUS users include the Data Processing System (DPS) Launch-Commit Criteria (LCC) Expert System (DLES) and the Propulsion Advisory Tool (PAT). Additional documents are being added to the database.

Key accomplishments:

- 1992: Demonstration of the network protocol to the user community.
- 1993: UCMS phase one demonstration and release to the user community.
- 1994: Database server demonstration to the user community.

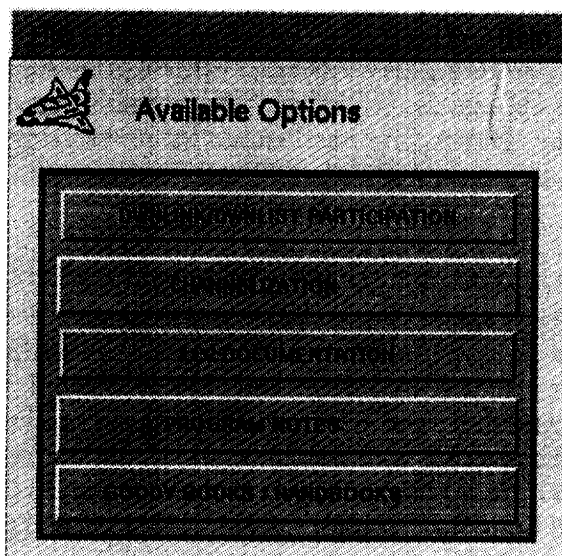
Key milestones:

- 1995: UCMS first-in/first-out data support. Database server completion. MOSAIC interface to the database server for UNIX workstations, PC's, and Mac's.



Contact: J.H. Fluhr, TV-GDS-11, (407) 861-3788

Participating Organization: Lockheed Space Systems (J.M. DeVoss)



| Firing Rm 1 CCP | | Firing Rm 3 CCP | | ACTIVE SOURCES |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| SOURCE: | Firing Rm 1 CCP | | Firing Rm 3 CCP | Firing Rm 1 CCP |
| TCID: | SA063A | | SB066A1 | Firing Rm 3 CCP |
| STS NUMBER: | STS-83 | | STS-86 | |
| VEHICLE ID: | OV-103 | | OV-104 | |
| GMT: | 2013/33.975 | | 2013/33.872 | |
| PACKET COUNT: | 378 | | 377 | |
| ERROR COUNT: | 0 | | 0 | |
| DATA VALID: | YES | | YES | |
| DATA LOGGING: | NO | | NO | |

| |
|---|
| 301:1600/53 EST - Firing Rm 1 CCP TCID: SA063A |
| 301:1600/55 EST - Processing data stream. |
| 301:1600/57 EST - Start Area 3: Firing Rm 3 CCP |
| 301:1600/57 EST - Firing Rm 3 CCP TCID: SB066A1 |
| 301:1602/40 EST - Starting db_control |

Propulsion Advisory Tool (PAT)

The idea for the Propulsion Advisory Tool (PAT) was born out of the frustration and delays incurred by the launch team at KSC in the summer of 1990. During the hydrogen leak investigations, the team had a difficult time assembling the data for evaluation. The system used to track the Main Propulsion System (MPS) during launch lacked robustness and speed due to strict configuration controls and the dated equipment. The only way the team could compare data was to tape it to walls and do a manual comparison. Another reason for the creation of PAT was that MPS is a major contributor to on-pad scrubs and troubleshooting efforts. It is a driver behind vehicle processing and, like other subsystems, is rapidly losing expertise due to ebbing design center and vendor support. As a result, these pools of knowledge are being lost forever. Hence, the need exists for an advisory computer system to track the MPS that is a knowledge-based system with user-friendly storage and retrieval of the data and data plotting.

PAT is a joint development project among KSC, Lockheed Space Operations Company, Lockheed Sanders, Rockwell International Space Systems Division (KSC), and Rockwell International Space Systems Division (Downey). PAT is an expert system that focuses on launch-day operations to monitor MPS health by following the transfer of liquid hydrogen and oxygen through the ground systems and orbiter into the external tank. To accomplish this, PAT relies on data from analog pressure/temperature sensors and discrete valve position indicators as well as data for the aft background purge effluent for liquid hydrogen, liquid oxygen, and helium leakage. PAT uses incoming data for two parallel operations. One path is used to display the MPS liquid oxygen and liquid hydrogen propellant loading system. The user can display plots of any applicable MPS measurements, in any combination. Historical data can also be plotted with "live" data. The other path feeds the PAT Knowledge Base. This expert system software uses a rule/model base of knowledge captured from MPS engineering experts to predict and detect anomalies or trends. The user is warned of potentially hazardous conditions in addition to suggesting a corrective action. The groundwork has been laid for use of neural nets in the PAT Knowledge Base.

The system software has been operational since the spring of 1992. The system hardware and liquid hydrogen software were also delivered in 1992. In 1993, additional hardware and the liquid oxygen software were delivered. Due to budget cuts in 1994, debugging of the system software was the only work done. However, the team received the NASA Group Achievement Award for accomplishments to date on the project. On the schedule for 1995 is the delivery of the liquid oxygen anti-geyser expert system software and delivery of the system software for the Space Shuttle Main Engines.

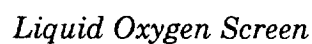
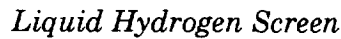
Key accomplishments:

- 1992: Initial demonstration of software technology. Implementation of initial liquid hydrogen data reduction/manipulation prototype. Delivery of hardware.
- 1993: Delivery of liquid oxygen data reduction/manipulation software. Delivery of hardware.
- 1994: Debugging of system software. Team received the NASA Group Achievement Award.

Key milestones:

- 1995: Complete the liquid oxygen anti-geyser expert system software. Deliver the data reduction/manipulation software for the Space Shuttle Main Engines.

Participating Organizations: Lockheed Space Operations Company (L.T. Bird), Lockheed Sanders (B. Houvener), Rockwell International Space Systems Division (KSC) (L.H. Fineberg), and Rockwell International Space Systems Division (Downey) (J. Marinuzzi)



Vehicle Health Management System

The primary task of KSC is to prepare the Shuttle and its payloads for launch into low Earth orbit. Due to its complex nature, this process is extremely labor intensive. The Vehicle Health Management System (VHMS) is a potential solution to automating some of these labor-intensive tasks. In order to prepare the Shuttle for launch and on-orbit mission day-to-day testing, the monitoring and diagnosis of Shuttle systems have to be carried out by a cadre of specially trained technicians and engineers. Much of this work is done in the firing room from automated test and checkout consoles. One of the key elements in Shuttle test and checkout is the integration console that helps to coordinate and oversee Shuttle operations. A primary pretest and checkout task is orbiter powerup activation of the Shuttle's Data Processing System, Environmental Systems, Electrical Systems, Instrumentation Systems, and the Orbiter Integration System. This is a labor-intensive task that requires engineering personnel from each of the five main subsystems to be present during powerup to monitor their respective systems. The VHMS project is tasked to reduce this labor requirement via software automation that would allow orbiter powerup and powerdown to be accomplished from only one console (Orbiter Integration System).

In order to automate this task, the advanced software laboratory joined efforts with the Orbiter Integration System console personnel to develop an automated monitoring and diagnostic tool for use in orbiter powerup and powerdown operations. This tool uses an advanced software system called KATE (Knowledge-Based Autonomous Test Engineer), which was developed specifically to perform automated monitoring and diagnosis of Shuttle electromechanical systems. KATE monitors and diagnoses a target system by comparing the behavior of an internal model of this target system with the actual system. If a discrepancy occurs, KATE verifies the occurrence of the fault and then initiates a set of diagnostic algorithms. Of the four systems employed during powerup and powerdown, it was decided to first start with the development of a KATE application for the Environmental Control and Life Support System (ECLSS) due to its relative simplicity.

Key accomplishments:

- Integration console selected KATE for firing room application.
- Orbiter environmental subsystem (Freon coolant loop) prototype developed for firing room use and use by the Orbiter Integration System console personnel.
- Began field testing of the KATE Orbiter environmental subsystem (Freon coolant loop).

Key milestones:

- Complete the field testing phase of the KATE Freon coolant loop.
- Complete/debug the KATE ECLSS application.

Contacts: P.A. Engrand and C.L. Parrish, DM-ASD, (407) 867-4181

Participating Organization: I-NET Space Services (C.H. Goodrich)



Wireless Information Network (WIN)

WIN is a proposed system to provide Payloads personnel with wireless access to the Payload Operations Network (PON) and its existing data systems via a remote, highly portable, self-contained computer. In a continuing effort to improve processing and enhance productivity, the Payloads Engineering Systems Division (CG-ESD-3) identified the need for accessing the PON in areas that do not support hardwire connections.

The feasibility of wirelessly augmenting the PON in the processing areas was investigated through a Small Business Innovation Research (SBIR) project. Off-the-shelf and custom approaches were researched. Existing off-the-shelf hardware was successfully demonstrated at the conclusion of the 6-month study. The ARLAN 680 Parallel Ethernet adapter with the ARLAN 610 Ethernet hub was the product demonstrated.

The system was first tested for electromagnetic emissions in a shielded enclosure located at KSC. The system was then demonstrated in the high and low bays of the Operations and Checkout Building. This area posed the highest probability of interference from the checkout systems, flight hardware, pyrotechnics, and metal structures. The system used radio-frequency spread spectrum at the 902 to 928 megahertz frequency range.

The ARLAN system consisted of a bulky parallel Ethernet adapter and a hub. The data rate was approximately 1 megabit per second. The range in dense office space was about 260 feet, while in the high bay it was approximately 75 feet. This system showed problems of accelerated battery depletion on the laptop computer as well as the transmitter/receiver.

The product suggested by SENTEL for implementation is the Solectek AirLAN system. This system uses a PCMCIA wireless network interface card that connects into a laptop computer. The AirLAN product employs a small, conformal antenna that easily attaches to the back of the laptop. The data rate is approximately 2 megabits per second.

However, the AirLAN system was able to connect to the PON, log onto the mail server, send/receive mail messages, and view documents on the network. During the demonstrations, initial software configuration and hardware problems were encountered but were overcome. The prototype was successfully demonstrated and established the technical feasibility of the project. SENTEL Corporation has been awarded a follow-on Phase II contract through the SBIR office. Phase II is a 2-year contract to provide a limited implementation of a wireless network system. Some of the innovations that will be developed in Phase II are: a solution to "roaming" and anytime, anywhere access requirements; a method to search and retrieve large documents practically; a new virtual addressing technique; environment (electromagnetic) sensing software; and a solution to reduce the accelerated battery depletion rates.

Key accomplishments (January to June 1994):

- Establishment of the feasibility.
- Successful demonstrations of the prototype.

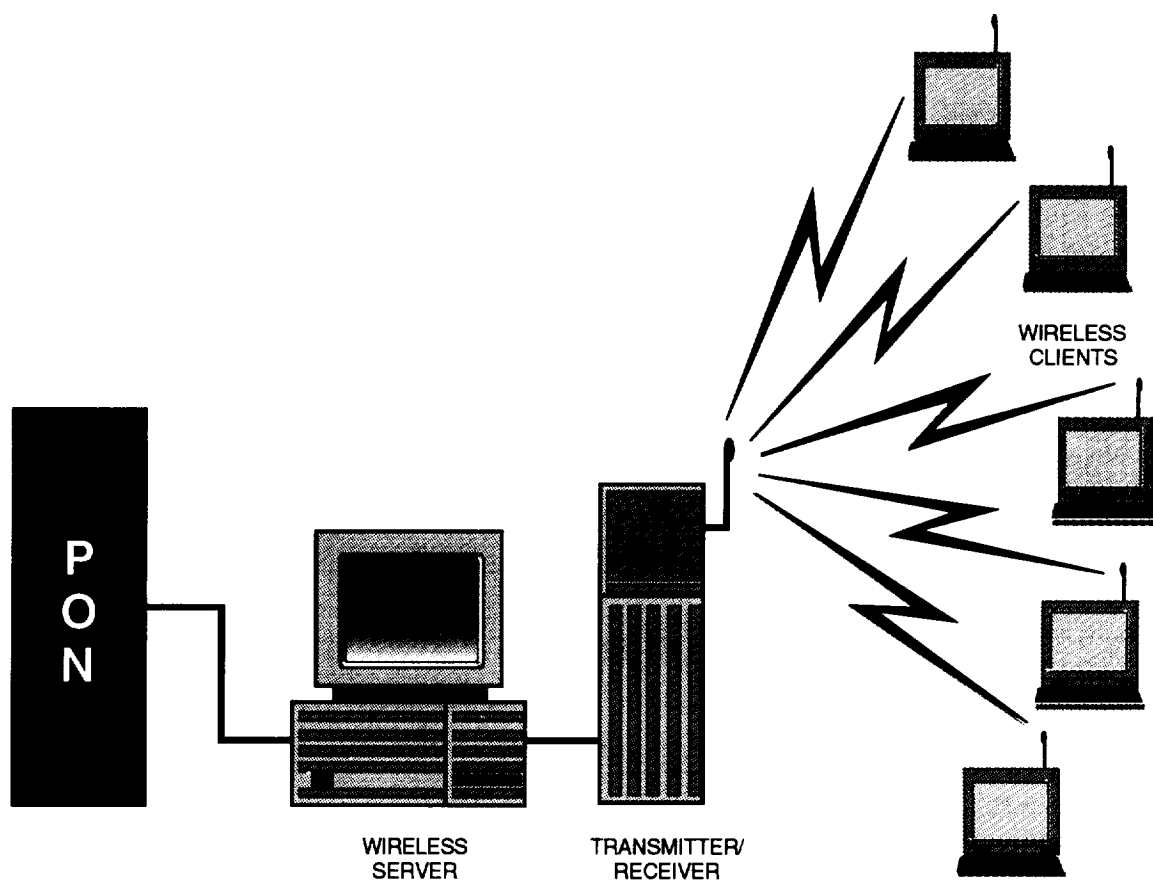


Key milestones (projected dates: March 1995 to March 1997):

- First year: Implementation of a wireless network test bed, including hardware and software. Research procedural and organizational impacts.
- Second year: Operational wireless network in processing facilities (limited implementation). Research the impacts and approach for a full implementation.

Contact: D.C. Manent, CG-ESD-3, (407) 867-9367

Participating Organizations: NASA (B. Boatright, S. Gwynn, J. Calero, M. Loughheed, E. Cody, R. Mizelle, M. Conroy, J. Nuñez, H. Denney, J. Shaver, E. Stoccardo, and F. Frazier), McDonnell Douglas Space Systems (R. Fussell), and SENTEL Corporation (E. Adolphe, P. Xantus, and F. Saeed)



Internet News Viewer (WinVN)

Network News, sometimes called Usenet News, is a distributed bulletin board system that runs on millions of computers worldwide. Government, educational, and commercial organizations utilize this system to discuss information in over 16,000 separate categories. Until recently, most computer programs that allowed access to the Usenet were based on high-end UNIX workstations. With the advent of a computer program called WinVN, it is now possible for relatively inexpensive personal computers running Microsoft Windows, Windows/NT, Windows/95, or OS/2 to send and receive messages on the Usenet.

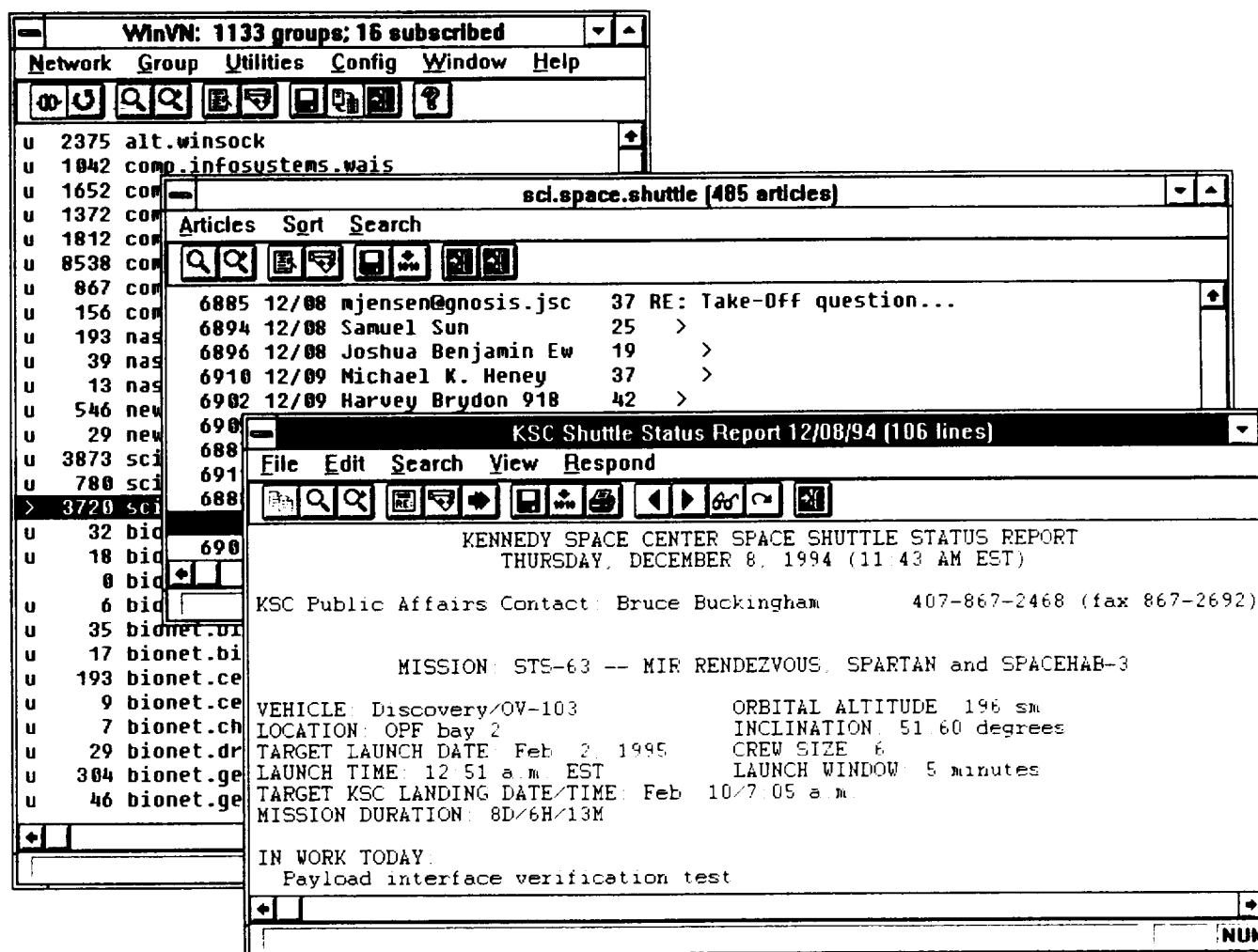
In 1992, the Payload Operations Ground Systems Information Systems Office (CG-ISO) needed a computer program to facilitate discussions about work authorization documents (WAD's) and procedures between NASA centers, universities, and international partners. This program was required to support the technical documentation subsystem of the KSC Payload Operations Data Management System (PDMS-II). PDMS-II is a collection of computer hardware and software systems used to support the processing of payloads for flight aboard the Space Shuttle. An electronic discussion method was needed because many people working on Shuttle ground processing documentation work on different shifts or in different time zones.

Instead of developing a KSC-unique solution, NASA software developers decided to enhance a Public Domain computer program written as part of a software contest by Mark Riordan of Michigan State University. After contacting Riordan, NASA agreed to make extensive enhancements to WinVN, coordinate an open Internet development effort to extend its features, serve as the overall integrator for future versions of WinVN, and release all enhancements and source code back into the Public Domain. The project became an international cooperative venture between NASA/KSC and various universities and private individuals.

WinVn uses the Transmission Control Protocol/Internet Protocol (TCP/IP) Windows Socket (WinSock) standard to provide a vendor an independent way to send text and binary encoded files between a Microsoft Windows application and the network. Users interact with WinVN using three types of windows: the main group-list window that allows a user to select a general category for discussion; one or more group article-list windows, each of which displays a list of ongoing discussions within that topic; and one or more article windows that contain the actual text of the discussion.

Key accomplishments and milestones:

- 1990: WinVN 0.73 released by Mark Riordan into the Public Domain.
- 1991: WinSock draft specification released, which paved the way to write portable network code for Windows.
- 1992: NASA/KSC took over development as part of PDMS.
- 1993: WinVN 0.82 released. Threading and vendor independent network support provided.
- 1994: WinVN 0.96 released. Commercial interest develops. Available in bookstores and CD-ROM.
- 1995: Release WinVN 1.00. New user interface; rewrite for supportability.



WinVN is in the Public Domain, and the latest versions for both Microsoft Windows and Windows/NT (source, binaries, and documentation) are available free of charge on the Internet via Anonymous FTP from FTP.KSC.NASA.GOV in the directory [pub.winvn]. Questions can be sent to the developers via the electronic mailing list "winvn@news.ksc.nasa.gov." People wishing to join the WinVN developers list can send an E-Mail message to "majordomo@news.ksc.nasa.gov" with a message body of "Subscribe WINVN." This mailing list is also gatewayed to the MAIL.WINVN newsgroup on the server NEWS.KSC.NASA.GOV. Online documentation is also online via the World Wide Web (WWW) WinVN Home Page at the Universal Resource Location (URL) of "http://www.ksc.nasa.gov/software/winvn/winvn.html."

Contacts: J.M. Dumoulin and S.M. Rushing, CG-ISO-2, (407) 867-3686

Participating Organizations: Michigan State University (M. Riordan) and FineLine Software, Inc. (J.S. Cooper)

Automated Database Design

Users and programmers of small systems typically do not have the skills needed to design a database schema from an English description of a problem. The goal of this project is to design and implement a system that will build a database design from natural language descriptions of KSC database problems, entered by users with no knowledge of databases or programming.

The system has two major components: (1) a natural language understanding (NLU) component that parses and understands the sentences typed by the user and (2) a problem-solver component that identifies the entities, attributes, and relations from the output of the NLU. This identification is one of the central problems that needs to be solved because entities in one problem description may be attributes in a different problem. The problem solver, a rule-based system, uses two knowledge sources to make a decision: (1) the database model (DBM) (an entity-relation model) under construction and (2) the final knowledge structures provided by the NLU. The problem solver consists of two distinct classes of rules: (1) generic rules that identify attributes, relations, and entities only on the basis of the attributes, relations, and entities already in the DBM and (2) specific rules that base their identification on semantic cues resulting from the semantic interpretation phase of the NLU. The specific rules that act as filters for those situations requiring special handling are fired first, followed by the generic rules. The NLU component has been under design for several years and has been extended and slightly modified for this task. There is a synergistic relation between these two components. As a result, a more robust problem solver can make up for shortcomings in the natural language component and, vice versa, a more robust NLU can compensate for a weaker problem solver. In this design, the system leans on the problem solver that takes care of discourse problems (such as resolution of anaphora, focus, etc.), which demand complex mechanisms for their solution and, in many cases, remain without satisfactory solutions in natural language processing.

The progress made includes continuous enhancements to the NLU system and the design and implementation of the problem solver. A prototype was finished that is able to construct entity-relationship diagrams for different kinds of KSC database problems. The system, written in Common LISP, runs on SPARC workstations.

Key accomplishments:

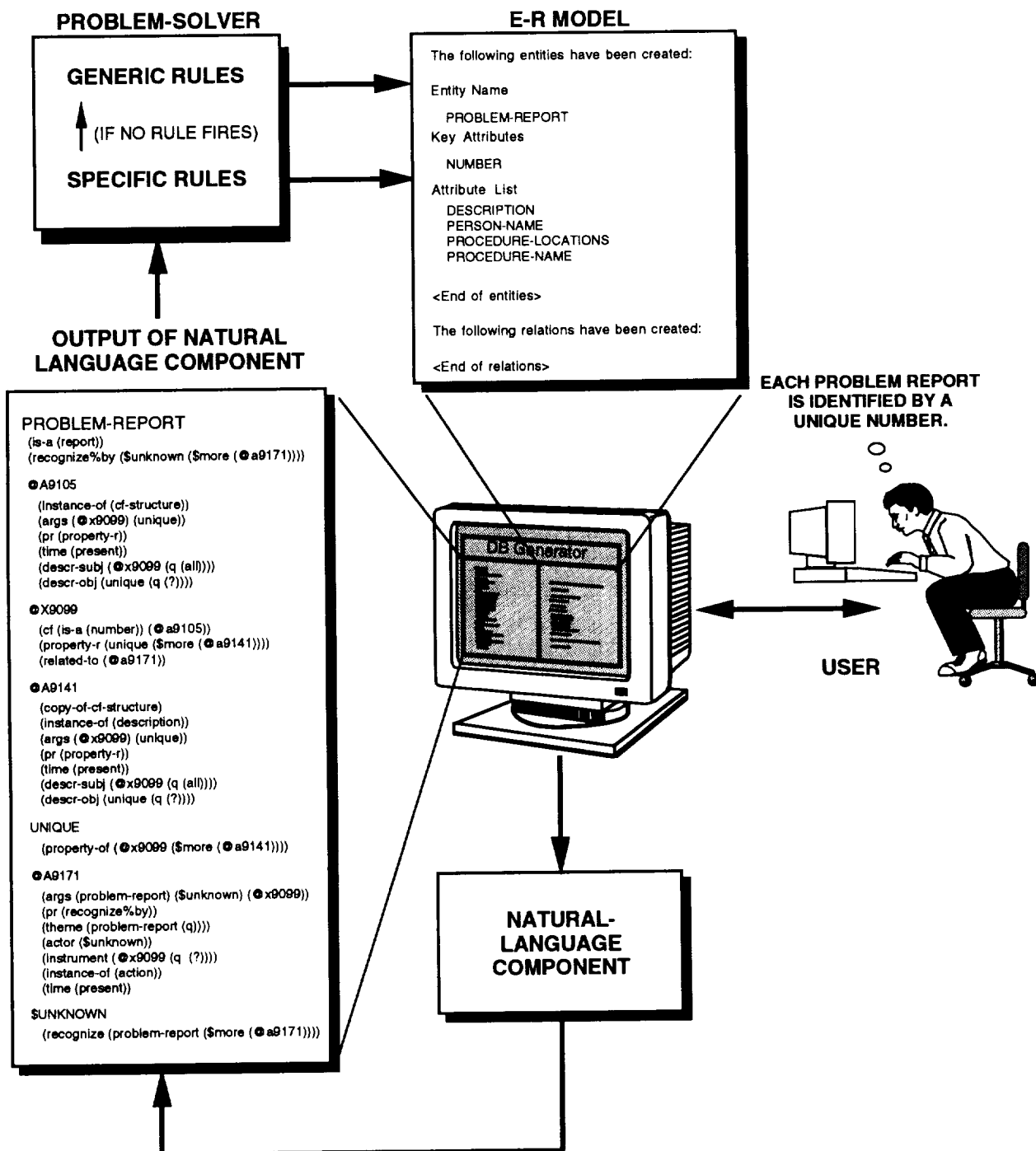
- 1993: Began project, made a literature survey, and completed the initial design of the system.
- 1994: Prototype completed and running.

Key milestones:

- 1995: Build a knowledge acquisition interface to the system. Incorporate case-based reasoning within the problem solver. Perform beta testing and assessment of the technology.

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Participating Organization: University of Central Florida (Dr. F. Gomez)



System Components and Goals

Shuttle Launch Measurement Processing Online Graphical Plot Capability and Online Launch Measurement Retrieval

Prior to 1994 immediately after each Shuttle launch, scrub, or abort, 14-track tapes of launch measurement telemetry data, at rates ranging from 60 to 100,000 samples per second, were processed and converted to engineering units by EG&G personnel in the Engineering Development Directorate (DE) CAD/CAE computer facility. The measurement data was then presented in graphical plots on hardcopy listings for NASA engineering and contractor engineering analysis. The telemetry data was copied to tape or optical disk for permanent archiving.

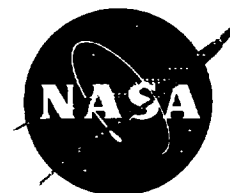
EG&G was tasked to provide a capability to assist the NASA Mechanical Engineering group in obtaining immediate access to measurement data for any past Shuttle launch. The old method of providing launch data required that engineers manually research all documentation just to determine which specific measurements were applicable for a particular area of interest. EG&G converted the telemetry data, produced a measurement data plot of the requested time interval, and extracted the actual data from the archive media to a DE CAD/CAE computer hard disk for an engineer to download to a remote workstation for more extensive analysis. This process could take several days. In addition to requests for historical data, hundreds of pages of plots were printed for each launch in support of various engineering launch analysis requirements. In summary, there were two basic problems with the old approach:

1. There was no efficient or timely method to determine which measurements were recorded for a specific structure (e.g., the Rotating Service Structure, launch pad, or Mobile Launcher Platform), type (e.g., pressure, strain, vibration, or acoustics), or launch (e.g., STS-1 or STS-66).
2. The hardcopy/paper measurement plots were cumbersome and expensive to produce and store.

The initial task was to provide a capability to quickly retrieve information about a specific measurement for a specific launch. Using an Oracle database on the DE Alpha 7610 computer, a large directory of measurements for prior launches was prototyped using STS-61. Digital Command Language (DCL) and Structured Query Language (SQL) were used to quickly create a simple, basic interface to the database. The second, larger task was to make the measurement data available to be plotted on the engineers' workstations via a remote network connection to the DE Alpha 7610. This second task required the following four technical requirements be satisfied, at zero cost, using existing equipment and software.

1. The telemetry data had to be moved from tape/disk to online direct access storage.
2. The software had to be developed that would interface the measurement database to the actual data on an online direct-access storage device.
3. The software to plot the data on the remote workstation monitors had to be obtained or developed.
4. Sufficient online direct access storage had to be allocated — an amount capable of storing large volumes of data from all Shuttle launches, scrubs, and launch aborts.

It was decided to use an existing optical disk storage device, an Alpatronix Inspire II jukebox, as an inexpensive alternative to hard-disk storage to record the large volumes of launch measurement data. The software interface between the engineers' workstations, the measurement database, and the data on optical disk was developed in house. A FORTRAN program was written in house to reproduce the plots as Postscript images. The Ghostview for X-Windows software was used to display the launch data from a



Postscript image. Ghostview was obtained from the Massachusetts Institute of Technology library of software via Internet, saving hundreds of hours of reprogramming.

Key accomplishments for 1994:

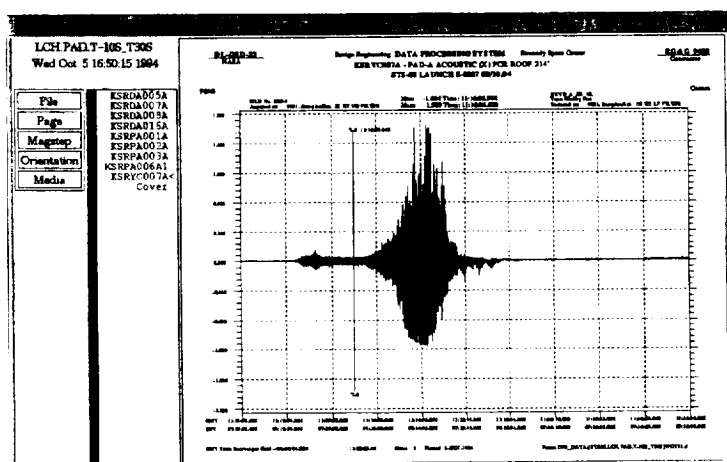
- Conversion of launch measurements, STS-26R through STS-66, to optical disk.
- Implementation of a measurement database and database retrieval function.
- Implementation of an online plot display of current launch measurements (see the figure below).
- Prototype of STS-61.
- Elimination of hard-copy graphic plots.

Key milestones:

- Measurement selection/display plot for the same measurement for selected time intervals.
- Telemetry data reduction of STS-1, STS-2, STS-3, and STS-7 and transfer to optical disk.
- Database conversion to support access to measurements for STS-1, STS-2, STS-3, and STS-7.
- Database conversion to support access to measurements for STS-26R through the present.
- Data retrieval for a selected measurement (download to local disk capability).

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Participating Organization: EG&G Florida, Inc. (P.S. Gemmer, K.R. Unger, S.A. Riley, L.L. Albright, R.A. Heyward, R. Vick, and M. Sorger)



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STS.COM          <<< KENNEDY SPACE CENTER >>>          DATE: 6-OCT-1994
                  STS LAUNCH MEASUREMENT DIRECTORY
                  QUERY SELECTION MENU

==> 1. DIRECTORY OF MEASUREMENTS FOR EACH LAUNCH (STS-58, STS-61)
    2. STS-68 LAUNCH, STS-68 ABORT, STS-64 MEASUREMENT PLOTS
    3. SELECT A MULTIPLE PLOT
    4. SUB-MENU TO LIST VALID MISSIONS, MEAS TYPES, STRUCTURES
    5. DOWNLOAD DATA TO A FILE
    6. DISPLAY GRAPHIC PLOT OF SELECTED MEASUREMENT FROM AN X-TERMINAL
    7. DISPLAY MEASUREMENT LAB DATA (MLD) SHEETS FOR LAUNCH SENSORS
    8. DISPLAY A MANUFACTURER SPEC DIAGRAM FOR LAUNCH MEAS. SENSORS

X. EXIT

ENTER NUMBER OF SELECTION: 2
    
```

Main Selection Screen for STS Launch Telemetry Measurements

Plot Display of Current Launch Measurements

Virtual Reality

The Advanced Software Laboratory's role is to investigate, understand, and disseminate new and alternative software and computer technologies that may be of use within the KSC community. One of these new and potentially powerful new information technologies is virtual reality. Virtual reality is a developing area of computer technology that uses a computer to create the illusion the user is virtually inside a three-dimensional simulation of an environment. Although virtual reality is used primarily today by the entertainment industry, new applications for use as design tools are being developed in civil and industrial engineering as well as in architectural fields. Due to virtual reality's unique ability to present complex information in a new way, other virtual reality applications have been developed for financial trading within commodities markets and for complex database applications.

In order to introduce this technology to the KSC community, the Advanced Software Laboratory has undertaken an initiative to develop a small-scale virtual reality capability that will allow potential KSC users to understand and apply this technology to KSC operations. This capability will include the purchase of sufficient hardware and software to support low-end to moderate virtual reality capabilities. In addition to this physical infrastructure, the laboratory is undertaking measures to identify the most likely users of this type of technology at KSC.

Key accomplishment:

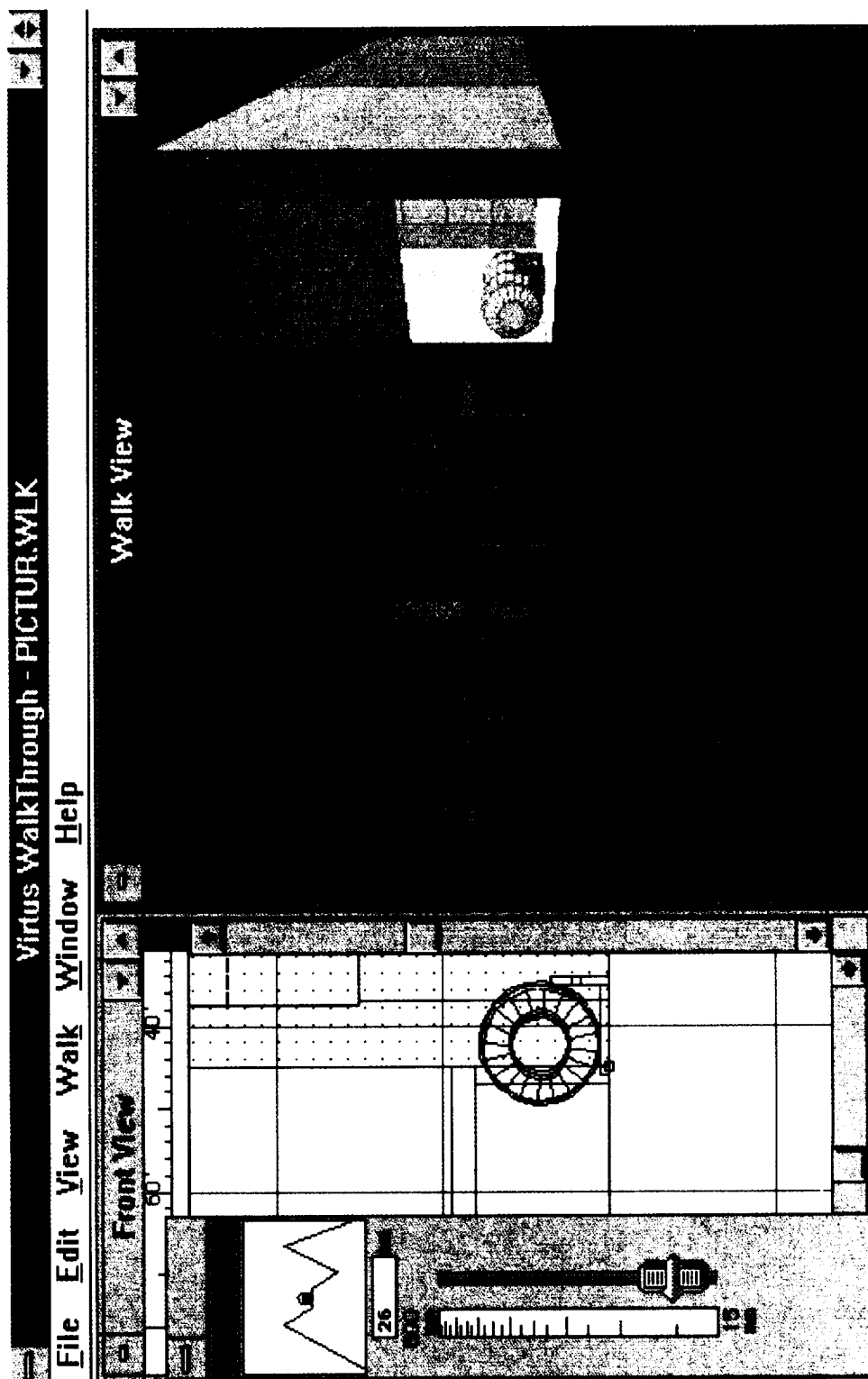
- 1994: Establish hardware/software resources for investigation of potential applications.

Key milestones:

- 1995: Disseminate virtual reality technology to potential users via demonstrations. Pursue potential virtual reality project applications.

Contacts: P.A. Engrand and C.L. Parrish, DM-ASD, (407) 867-4181

Participating Organization: I-NET Space Services (C.H. Goodrich)





The Nondestructive Evaluation (NDE) Technology program at the John F. Kennedy Space Center (KSC) includes the development of inspection and verification instruments and techniques that can provide information (external or internal) to hardware and component structures in a non-intrusive manner. The technology includes, but is not limited to, the following:

1. Laser
2. Infrared
3. Microwave
4. Acoustic
5. Structured light
6. Other sensing techniques
7. Computer and software systems needed to support the inspection tools and methods

Nondestructive Evaluation

The present effort in this discipline is being directed toward reducing Shuttle processing costs using these technologies. The long-term effort of the program is to develop cost-effective NDE techniques for inspecting and verifying space vehicles and their components during manufacture and to continue validating those items during assembly/launch and on-orbit or during space flight.

Ultrasonic Leak Detector

During the summer of 1990, main propulsion system leaks in the aft and at the 17-inch disconnect on STS-35 and STS-38 were detected by mass-spectrometer-based leak detection systems and catalytic bead hydrogen sensors. Once the leaks were detected, locating the source of the leaks for correction proved to be more difficult. During the effort to locate the source of leaks, it was proposed to use ultrasonic transducers to attempt to hear the sound produced by the leaks. Prototype equipment was built and used during the leak location efforts. The ultrasonic equipment found a small leak in the area of the aft at which it was aimed, but this leak was well below the criteria that prevents launch. The large leak that prevented launch was found during this test in another area and subsequently fixed. Nevertheless, this test demonstrated the effectiveness of ultrasonics for locating leaks. The use of ultrasonics for locating leaks in other fluid systems and critical ground support equipment was then proposed, and work in this area has continued. Recently, these efforts have produced impressive tools for locating leak sources.

Jet-type leaks (i.e., leaks that are not laminar) create turbulent pressure variations that can be detected with an ultrasonic transducer. Consequently, by developing very sensitive ultrasonic detection equipment, small leaks can be located quickly from a remote location. After consideration, it was decided the following areas warranted study for potential design improvements over off-the-shelf instruments (specifically the UltraProbe 2000, which was borrowed for comparison studies): choice of transducers, preamp design, processing circuit design, air-coupled-system collector design, and contact-system transducer design.

It was determined a new ultrasonic transducer, the 40R16A, a 40-kilohertz ultrasonic receiver from American Piezo Ceramics, had slightly higher sensitivity and almost half the noise of the Panasonic unit. Therefore, use of this new transducer, coupled with a new preamp design, provided twice the performance of the Panasonic unit. An innovative processing module was constructed to downconvert the ultrasonic signal to the audio frequency range so a user could listen to the ultrasonic signals using a pair of headphones. A significant improvement over off-the-shelf systems was achieved by the use of collecting horns. These horns collect and focus the ultrasonic signals in the air onto the transducer, significantly improving the system performance.

In some cases, operations personnel need to locate ultrasonic leaks at close range (e.g., along a seam). For these cases, an ultrasonic pencil was delivered, which is essentially the same as the transducer geometry previously described but with the horn removed, allowing the transducer to be moved closer to the potential leak source. The proximity of the transducer to the seam more than makes up for the removal of the collecting horn and allows for sensitive leak detection.

Key accomplishments:

- Development of high-performance ultrasonic leak detector systems utilizing innovative circuitry, improved transducers, collecting horns, operator-friendly design, near-field configurations, and contact sensors.
- Delivery of four of these units to operations for field testing.

Key milestone:

- Awaiting input from field testing to determine the next step in this project.



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Participating Organizations: I-NET Space Services (Dr. R.C. Youngquist and R.B. Cox) and Rocketdyne



Laser Shearography

Laser shearography is proving to be a powerful tool in the detection of debonds and voids in many different materials, such as laminates, composites, honeycomb structures, and foam insulation. However, before the instrument can be used on flight hardware, its operational characteristics must first be standardized. This process involves systematic testing of the instrument to determine its capabilities and limitations. Once this testing is complete for a particular material, the methodology for inspecting that material can be standardized. This standardization must include material excitation parameters (i.e., pressure differential if using vacuum stressing), probability of detection curves, and confidence factors associated with the probability of detection. Also of importance is the investigation of all potential areas of application of this technology on the orbiter, external tank, and solid rockets. This research must include not only the areas of possible use but also the modes of material excitation in a given area.

The work currently being done on the laser shearography project consists of baselining the instrument for use in detecting debonds in the spray-on foam insulation (SOFI) on the external tank. The baselining is being conducted on test panels with programmed debonds and voids. The test panels consist of a 24-inch-square aluminum substrate covered with a primer. The panels are then sprayed with SOFI to an average thickness of approximately 3 inches and are then planed off to a uniform thickness of 1.5 inches. There are currently four completed test panels with programmed debonds and voids. The debonds and voids range in size and geometry in order to maximize the test information. The excitation mode will primarily be vacuum, as preliminary results indicate this is the most efficient method. While holding the foam thickness constant, each test panel will be run incrementally through a range of pressures (0 to 25 inches of water) to determine if the defects present on the panel can be detected. The foam thickness of each panel will then be reduced by 0.250 inch, and the process will be repeated until the foam thickness of each panel is reduced to 0.5 inch. The data will then be assembled into a three-dimensional "detection matrix," with one dimension being pressure differential, one dimension being defect size, and the third dimension being foam thickness. The elements of this matrix will indicate whether or not a defect was detected and, perhaps on a qualitative sliding scale, the level of visibility of the defect. With this detection matrix, an operator should be able to determine what size defect should be visible (if present) at a given foam thickness and pressure. This should provide a first step to standardizing the instrument for use on foam applications. Other data will also be taken. This data includes the shear vector, location, extent, aspect ratio, and orientation. This data, combined with that used to construct the detection matrix, should provide a database sufficient to perform the statistical analyses necessary to produce a meaningful probability-of-detection curve. Together, the detection matrix and probability-of-detection curve will allow the user to state within a certain confidence level that the area under observation is free of defects.

A vacuum chamber of sufficient size to fit a 24-inch-square test panel was constructed from 3/4-inch Plexiglas. The vacuum chamber is fitted with a vacuum gage so the pressure differential can be monitored during testing. Testing has begun on the four test panels, and the detection matrix is being constructed. Debonds on the order of half the foam thickness in diameter were observed with pressure differentials as small as 2 inches of water (0.07 pound per square inch). Also, while the vacuum chamber was operational, other areas of laser shearography application were investigated. Test panels consisting of 1-inch-thick ablative material and K5NA were inspected, and debonds were successfully detected in both these materials at pressure differentials similar to those previously discussed. These preliminary tests indicate there are numerous other areas of application for laser shearography at KSC. Future plans for this work include qualifying the instrument for use on flight hardware, inspecting flight hardware, defining new areas of application, image processing to yield more quantitative information, and perhaps building specialized laser shearography heads to facilitate use of laser shearography technology in areas of difficult access.



Key accomplishments:

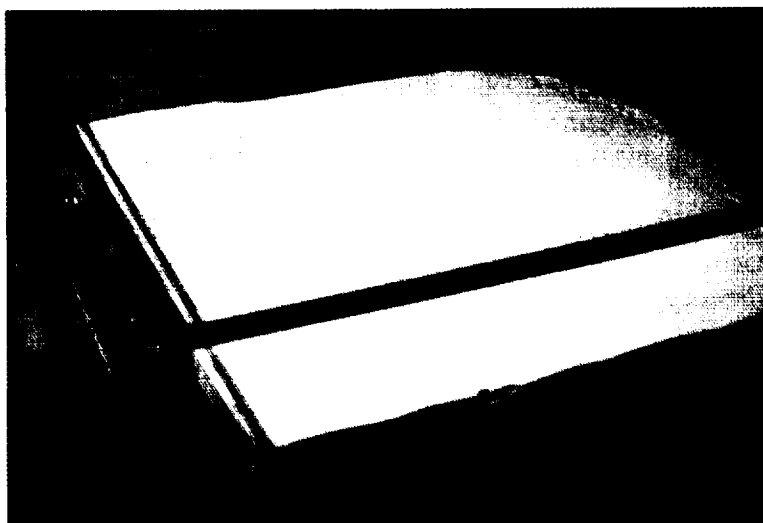
- Successfully detected debonds and voids in a variety of materials.
- Began the systematic testing necessary to generate meaningful probability-of-detection curves.
- Defined new areas of application on the orbiter, external tank, and solid rocket motors.

Key milestones:

- Qualify the instrument for use on flight hardware.
- Inspect flight hardware.
- Investigate defect quantification by use of laser shearograms.

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Participating Organization: I-NET Space Services (J.A. Hooker and S.M. Simmons)



SOFI Test Panel in Vacuum Chamber



Laser Shear Cart

Detection of Corrosion Under Paint

Corrosion on flight hardware is a problem becoming more significant as the Shuttle fleet ages. Most flight structures are painted, which makes detecting corrosion difficult. If the corrosion is allowed to become severe enough, it is detectable due to bubbling of the paint. However, once the corrosion has reached this stage, corrective action is more serious, costly, and time consuming. At this time, there is no method of detecting the early stages of corrosion under paint when the corrective action has little impact. The method used now on flight hardware is to guess where corrosion might occur, strip the paint, correct any corrosion that exists, and then repaint the area. This is a very inefficient and labor-intensive method. A method of detecting corrosion under paint during the early stages would save time and money.

The goal of this project is to develop a prototype system that can detect the early stages of corrosion under paint. To be an effective tool, the device must be capable of scanning large areas of flight hardware in a rapid fashion. The technique being explored to achieve this goal is a variation of thermography. The surface in question is thermally excited briefly while being observed with a high-resolution infrared camera with a fast response time. The surface will absorb the infrared and begin to conduct this heat back to the surrounding air. The region with corrosion will lose its heat more slowly than the uncorroded region. The infrared camera observes this behavior and transfers the sequence of infrared video images to a computer. The computer compares the rate of heat transfer of the surface on a pixel-by-pixel basis. From this information, a map of the corrosion under the paint can be made.

At this point, the basic technology has been demonstrated. An infrared camera with the necessary resolution has been procured. Some test articles were obtained from Johnson Space Center and the Materials Science Laboratory at KSC, and preliminary testing on these samples was performed. The next phase will be to develop an instrument that incorporates the infrared camera and the appropriate image processing software and mounting hardware that can be tested on the wing spars of the orbiter in the Orbiter Processing Facility.

Key accomplishments:

- 1993: A proof of concept using an infrared camera with moderate resolution was achieved.
- 1994: A higher resolution infrared camera was procured and tested with less severe corrosion samples.

Key milestone:

- 1995: A prototype capable of scanning a wing spar for corrosion will be designed and built.

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Participating Organization: I-NET Space Services (Dr. S.M. Gleman, S.W. Thayer, D.L. Thompson, and J.S. Fairbanks)



Miniature Hydrogen Fire Camera

Detection of hydrogen fires is an ongoing concern at all NASA facilities that use cryogenic fuels. The existing detectors suffer from drift and false alarms or are very expensive. Several efforts are underway to upgrade or replace these installed systems. This project aims to develop an inexpensive miniature hydrogen fire-imaging system that could be used in field installations to detect hydrogen fires.

It is believed that by imaging hydrogen fires the existing false alarm situation can be alleviated. Current advances in technology have made it possible to propose the development of a small inexpensive infrared (IR) camera that utilizes a 64 by 64 PbS or PbSe array. These arrays are stable and rugged but are not sensitive enough to be used to image a region. Consequently, the arrays will be boresighted with a small black and white visible camera that will supply timing information and produce a visible video signal when no significant IR image is present. Then, when an IR source appears (i.e., a fire), the output from the PbS array will be processed and superimposed onto the visible camera output signal. The result of this approach should be a small, rugged, and inexpensive fire-imaging camera.

After a preliminary design and startup period, a 64 by 64 element PbS array was ordered. Manufacturing problems delayed the delivery of this unit until October 1994. Work will begin in the near future to construct an IR camera from this array.

Key accomplishment:

- Received a 64 by 64 PbS array.

Key milestone:

- Construct a miniature, low-cost, fixed-field-of-view, infrared/visible camera that will allow detection of hydrogen fires in the field.

Contacts: J.D. Collins and M.J. Verdier, DL-ICD-A, (407) 867-4438; H.N. Delgado, RM-INT, (407) 867-3163; and H. Barnes, SSC/KA-60

Participating Organization: I-NET Space Services (Dr. R.C. Youngquist, W.D. Haskell, R.B. Cox, J.P. Strobel, and J.S. Moerk)

Reinforced Carbon Composite

The reinforced carbon composite (RCC) structures on the orbiter must withstand the highest temperatures and most severe stresses of any area of the orbiter. These structures were originally believed to withstand these temperatures and stresses without difficulty; however, an unanticipated problem has arisen. The heat of reentry caused pinholes to appear in the RCC panels. The cause and the extent of the problem are not completely understood. A system that maps the pinholes would be beneficial in determining the extent and ramifications of this problem.

The initial phase of this project will be to map the pinholes in the RCC panels in representative areas. An optical scanning device designed to be moved across the surface of the RCC panels will be used to image the pinholes. The images will be transmitted to a computer, which will create maps of the panels in the representative areas. Maps will be made before and after missions on various orbiters to determine if the amount of pinholes increases. This information will be transmitted to Johnson Space Center (JSC) personnel for analysis.

To this point, a proof of concept was demonstrated for imaging pinholes in the RCC, and a prototype system that utilized a handheld optical scanning instrument was built. Also, prototype image mapping software was written. The system was tested in the laboratory on an RCC panel with pinholes, and a map of the panel with the pinholes in the areas of interest was made. The next phase of the project will be to develop a system that can be used on the orbiter in the Orbiter Processing Facility. This system will be tested, and baseline data will be obtained for various RCC panels. The panels will be mapped again after future missions. JSC will use this information to assess the seriousness of the problem.

Key accomplishment:

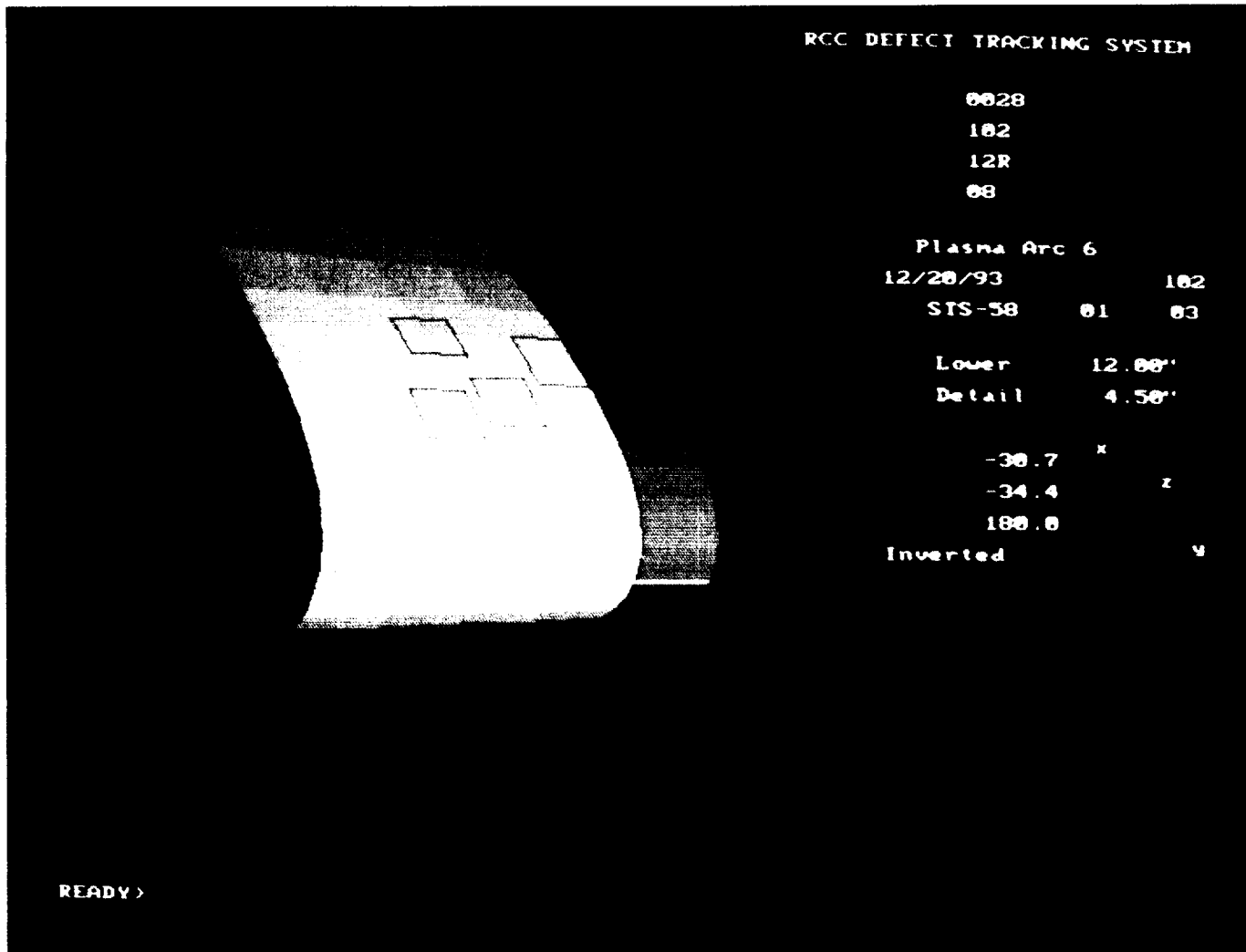
- 1994: A proof of concept was demonstrated.

Key milestone:

- 1995: A field evaluation prototype will be designed, built, and tested.

Contacts: J.D. Collins and M.J. Verdier, DL-ICD-A, (407) 867-4438; H.N. Delgado, RM-INT, (407)867-3163; and C.G. Stevenson, TV-MSD-1, (407) 861-3603

Participating Organization: I-NET Space Services (Dr. S.M. Gleman, S.W. Thayer, D.L. Thompson, and C.G. Hallberg)



RCC Flaw Detection CRT Screen

Orbiter Window Inspection System

Inspection of the orbiter windows is a task that must be performed during each flow process in the Orbiter Processing Facility. This inspection is currently performed manually by technicians using a high-intensity light source and a magnifying glass. The technician moves very slowly over each window with the magnifying glass and light source and attempts to find all the defects on the window. Each defect found is marked on a Mylar map of the window. Later, the defect's depth is measured using the mold impression technique. This information is then sent to Johnson Space Center (JSC) where engineers perform stress analysis studies to determine if the windows are safe for flight. The inspections are tedious and difficult to perform, and defects are occasionally missed. In one instance, a window was replaced at the launch pad because a defect was discovered that had been missed during the inspection. The goal of this project is to develop a tool that will not replace the human inspector but rather will reduce the likelihood that defects are missed by making the process more systematic.

The thrust of this project has been to develop a small, lightweight motion base that can accurately move an instrument package in X and Y directions across each orbiter window. The device will carry two instruments: one is an optical scanning device to map the defects and the other is a refocus microscope to measure the depth of the defects. A computer system will control the motion base, take data from both instruments, and act as an interface for the operator. The optical scanning device is a modified, commercially available document scanner. The motion base moves the scanner across the window in a precise repeatable pattern, and the information from the scanner is sent to a computer that evaluates the data and determines what represents actual defects. The computer creates a map of the window and shows defects from this data. After the window has been scanned, the device will return to each defect to allow the operator to use the refocus microscope for measuring the depth of each defect.

The refocus microscope is essentially a microscope with a very narrow depth of focus. Only objects at a specific distance from the microscope are in focus. Once the refocus microscope is placed over a defect, the operator controls its height above the glass using the built-in computer controls. The operator focuses the instrument on the deepest portion of the glass and then focuses on the surface of the glass. The operator indicates to the computer when the device is in focus for both points. From this information, the computer can determine the maximum depth of the defect. Once the window has been scanned and all the defects have been measured, the computer can print a Mylar map of the window, or the information can be stored electronically for archival information or for electronic transmission to JSC.

Initially, a proof-of-concept prototype was built that could scan window 4. This device was designed, built, and tested in the laboratory. A scrap window pane was used as a test article. This first prototype was tested on an orbiter in December 1993, and a second-generation prototype was then proposed. This device was to be able to scan all six windows and would first incorporate the scanning capability; then, the refocus microscope capability would be added. At this time, the second-generation prototype with the scanning capability has been built and tested on the orbiter. The refocus microscope device has been built, and integration with the scanner is underway.

Key accomplishments:

- 1993: Designed, built, and tested the first-generation prototype.
- 1994: Designed, built, and tested the second-generation prototype.



Key milestones:

- 1995: Design, build, test, and certify two production systems for windows 1 through 6.
- 1996: Design, build, test, and certify one production system for windows 7 and 8.

Contacts: J.D. Collins and M.J. Verdier, DL-ICD-A, (407) 867-4438; H.N. Delgado, RM-INT, (407) 867-3163; and C.G. Stevenson, TV-MSD-1, (407) 861-3603

Participating Organizations: I-NET Space Services (Dr. S.M. Gleman, S. W. Thayer, C.G. Hallberg, and J.E. Thompson); Lockheed Space Operations Company (G. Jensen); and Rockwell International Corporation (S.E. Holmes)

Smart Bolt Tension Analyzer

Determining the tension in bolted joints is a critical measurement for flight hardware such as the external tank umbilical studs, vertical tail bolts, Shuttle carrier aircraft attachment bolts, and other consequential bolts. Most of these measurements are performed with an ultrasonic tension-measuring device. These devices work by sending an ultrasonic pulse into one end of a bolt. The pulse travels down the length of the bolt and is reflected back. The transducer that sent the pulse can also detect the echo. The device then determines the time of flight of the pulse that was sent down the bolt. This measurement is taken twice, before and after it has been tensioned. The measurement device can determine the tension in the bolt based on the change in the time of flight of the ultrasonic pulse and the error of such devices is typically 2 to 3 percent under good conditions. However, the ultrasonic pulse can sometimes be reflected off the sides of the bolt in addition to the back end of the bolt, which causes constructive and destructive interference that distorts the shape of the pulse. This pulse distortion is called peak splitting or peak merging. The measuring device can trigger at the wrong instance if the pulse shape is distorted, which is called peak jumping. The error for a measurement that has jumped peak can be as high as 30 percent, and there is no reliable way to predict whether or not a bolt will be prone to peak jumping.

The goal of the project was to develop a prototype instrument to measure the tension in bolted joints that was not prone to peak jumping. Existing ultrasonic tension-measuring devices use circuitry that detects the pulse sent into the bolt to start a timing circuit and then detects the return pulse to stop the timing circuit. The approach used in this project was to digitize the pulse produced by the transducer and store it in the computer. Then the return pulse, which will have some distortion, is also digitized and stored in the computer. The computer performs a correlation calculation on the two waveforms that compares the degree of similarity as a function of time. The point in time when this function is at its maximum is related to the time of flight of an ultrasonic pulse traveling through the bolt. This is performed before and after the bolt is loaded, and the computer uses the difference in the time of flight to determine the tension in the bolt. Because the entire waveform and its echo are compared to determine the time of flight rather than one specific point on each waveform, the result is less susceptible to error caused by waveform distortion. The result is an instrument that will always have 3 to 4 percent error, but never 30 percent.

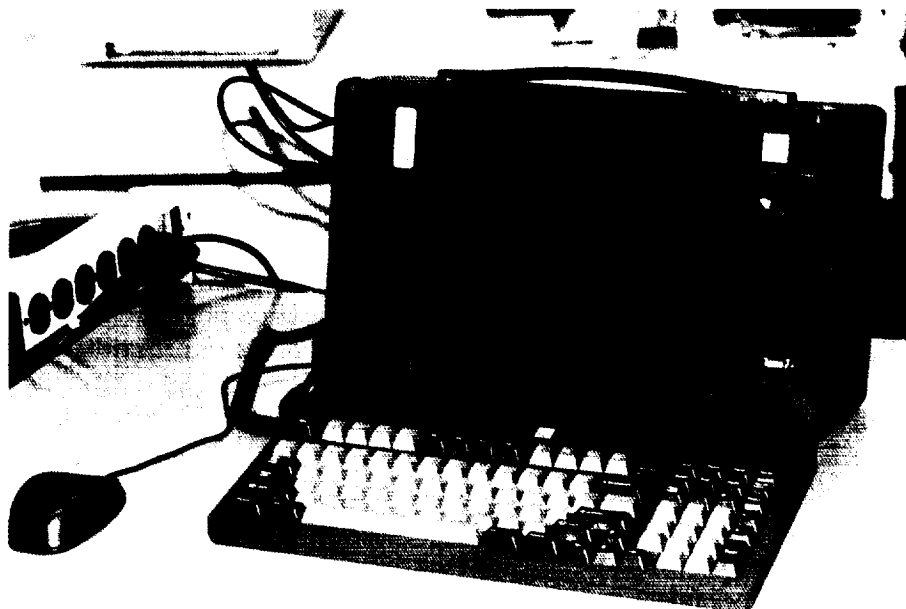
A complete prototype was built and tested in the laboratory and the field. The results of this testing were favorable. A first draft of the final report documenting the specifics of the correlation and discussing the testing was written.

Key accomplishments:

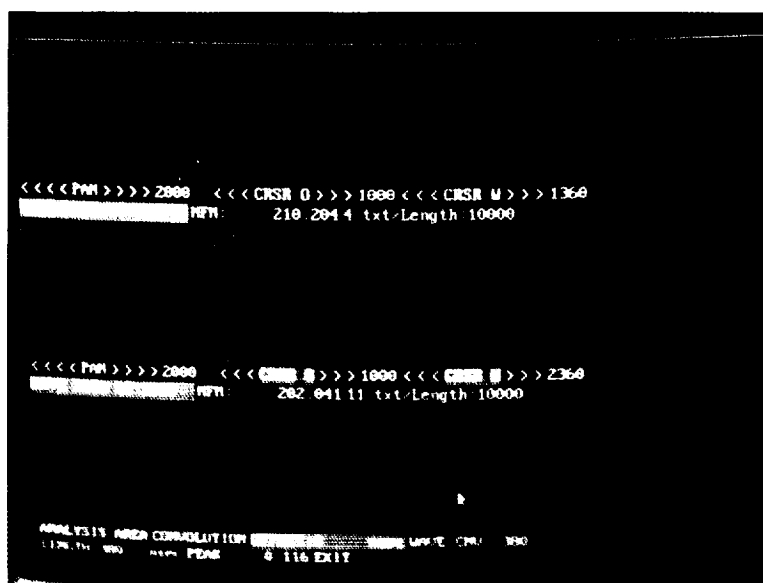
- Examined various methods of correlating the first pulse and second pulse.
- Selected the best correlation technique and fabricated a prototype system using it.
- Tested the prototype both in the laboratory and field.
- Edited the final report documenting the progress.

Contacts: J.D. Collins and M.J. Verdier, DL-ICD-A, (407) 867-4438, and C.G. Stevenson, TV-MSD-1, (407)861-3603

Participating Organization: I-NET Space Services (Dr. S.M. Gleman and S.M. Simmons)



Computer for Smart Bolt



Screen for Smart Bolt

Surface Defect Analysis

Inspection of flight hardware at KSC is a normal portion of each flow process that ensures Space Shuttle safety. Critical surfaces of flight hardware are inspected routinely for surface defects such as gouges, scratches, dings, or corrosion pits. Typically, two methods are used to evaluate the depth of these surface defects: mold impression and optical micrometry. Mold impressions are labor intensive, usually taking 4 hours to completely evaluate a surface defect, and the measurement is documented as a notation on a problem report. Optical micrometry is not as labor intensive as mold impressions, but the measurement is also documented as a notation on a problem report. On the average, 300 surface defects must be evaluated and documented during each flow process for the orbiter alone. The members of the nondestructive evaluation groups that must perform these evaluations have expressed a desire to be able to perform these measurements in a more timely fashion, thus providing better documentation. It was requested that a near instantaneous method of electronic mold impression be developed.

The goal of this project was to develop a device that could perform surface defect analysis on flight hardware in a time-effective fashion. The device was to be portable and safe for contact with flight hardware. Finally, the device was to make documentation of the defect easier. A portable system that utilized structured light microscopy was designed, built, and tested. Structured light microscopy involves projecting a line on the surface to be evaluated at an acute angle, while observing the surface with a video camera at the perpendicular to the surface. A computer captures this video image, and the operator makes the measurement. If the projected line strikes a flat surface, the image will have a straight line on it. If the projected line strikes a surface with some type of surface defect, the line will be deflected along the contour of the defect. Measuring the deflection of the projected line is indicative of the depth of the defect. To use the device, the operator takes a pair of suitcases containing the equipment to the location of the defect. The device is set up, which normally takes 2 or 3 minutes, and the operator holds an optical device over the defect. The operator positions the optical device over the defect with one hand and, with the other, holds the small monitor that displays the defect. Once the optical head is positioned satisfactorily, the operator captures the image on the monitor and sends it to the computer in the suitcase. Using this image and the software built into the computer, the operator determines the deflection of the line. The computer determines the depth of the defect using this information. The width of the defect can also be determined by the system. A printer built into the second suitcase can then be used to print a problem report for the defect, which includes a hardcopy printout of the image captured by the computer and the depth and width of the defect.

At this point, a proof-of-concept prototype has been built and tested. This unit worked well but was too bulky to use effectively. A more field-friendly prototype was built and tested and was much more compact and easier to use. It could measure surface defects from 0.0002 to 0.02 inch deep and 0.0002 to 0.02 inch wide with a resolution of 0.0002 inch in both cases. Field evaluation testing was performed by the various nondestructive evaluation inspectors. The response to this second-generation prototype was very favorable. Future objectives of this project are to design and build certified units that can be used operationally. In addition, special optical probes will be designed and built to work in areas that the basic unit cannot be used in due to limited space or cramped geometry or that require a larger measurement range. These will be designed as special end-effectors that can be plugged into the standard computer box.



Key accomplishments:

- 1993: First proof-of-concept prototype was built and tested.
- 1994: Second prototype was built and tested.

Key milestones:

- 1995: Design and build special optical end-effectors for difficult access areas. Begin to revise the design of the system to meet ground support equipment (GSE) design requirements.
- 1996: Complete the design of the system to meet GSE design requirements.
- 1997: Build and document two GSE versions of the surface defect analysis device.

Contacts: J.D. Collins and M.J. Verdier, DL-ICD-A, (407) 867-4438, and C.G. Stevenson, TV-MSD-1, (407)861-3603

Participating Organization: I-NET Space Services (Dr. S.M. Gleman, D.L. Thompson, C.G. Hallberg, and S.W. Thayer)



The Life Sciences Technology program at the John F. Kennedy Space Center (KSC) supports the development of advanced technologies for application in long-term human habitation in space. This effort is directed toward ensuring crew health, improving personnel comfort and safety, and improving operational efficiency in Controlled Ecological Life Support System (CELSS) biomass production, food processing, and preparation. The near-term focus of this program is CELSS resource recovery and biomass processing improvement techniques. The long-term focus will concentrate more on production improvement, emphasizing supply-line economics.

Life Sciences

Light-Emitting Diodes for Plant Growth

One of the main challenges for growing plants in space is supplying a sufficient quantity and appropriate quality of light. Potential electric light sources must have a high electrical efficiency, small mass and volume, an excellent reliability and safety record, and an optimal spectral output for photosynthesis and photomorphogenesis. Light-emitting diodes (LED's), particularly in the red region of the spectrum (660 to 690 nanometers), may meet this criteria. LED technology, as it applies to growing plants, is relatively new and few studies have been conducted to show its potential usefulness. Further research is necessary prior to the acceptance of LED's for supporting plant growth in space. Toward this end, the Plant Space Biology Laboratory at KSC, in collaboration with the Ames Research Center Gravitational Biology Facility Group and Dr. A.C. Schuerger at Disney's EPCOT Center, is conducting research on the growth, structural and reproductive development, photosynthetic characteristics, and disease resistance of a number of plant species grown under LED's.

Maximal rates of oxygen evolution (a measure of photosynthesis) are lower in wheat plants grown under red LED's as compared to control plants grown under cool white fluorescent lamps (see the figure "Photosynthesis of Wheat Leaf Discs From Plants Grown Under Red LED's"). This holds true whether the plants are grown at a high ($500 \mu\text{mol m}^{-2} \text{s}^{-1}$) or low ($50 \mu\text{mol m}^{-2} \text{s}^{-1}$) light intensity.

Wheat reproductive development is delayed in plants grown under red LED's compared to those grown under daylight fluorescent lamps (see the figure "Wheat Plants Grown Under White Light, Red LED's, or Red LED's Supplemented With 1 or 10 Percent Blue Light"). The addition of 10 percent blue fluorescent light enhances the rate of development in the red LED-grown plants.

Overall, these studies suggest that red LED's, in combination with a blue light source, may be a viable light source for growing plants in space. Future plans include determining the influence of red light and the threshold level of blue light on photosynthesis, chlorophyll biosynthesis, carbohydrate metabolism, and final yield.

Key accomplishments:

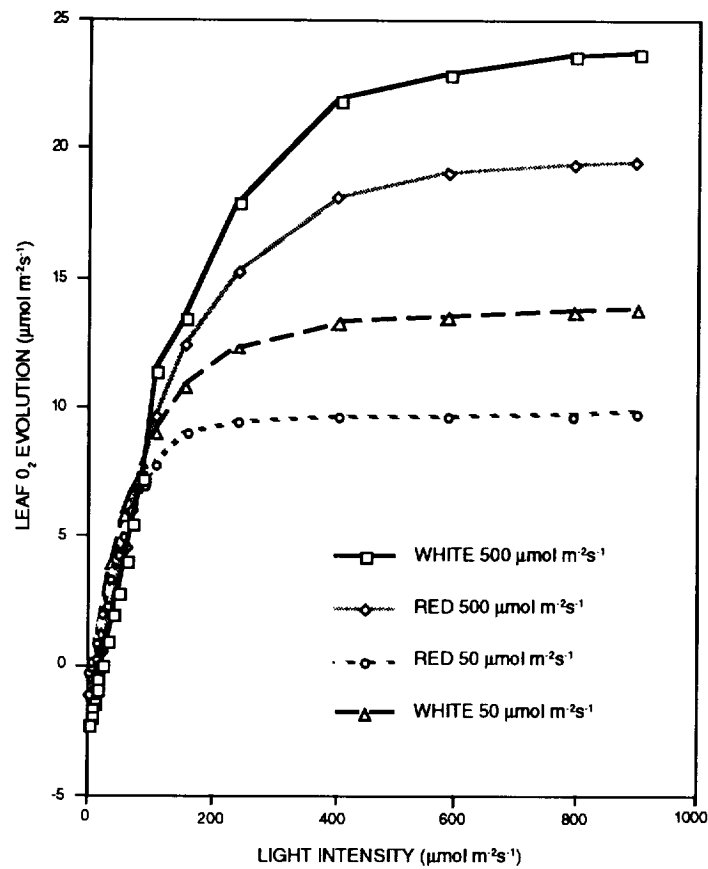
- 1992: Began experiments to assess LED's for plant growth.
- 1993: Continued experimentation on a number of different species under LED's. Began work on photosynthetic electron transport and chlorophyll biosynthesis.
- 1994: Began "seed-to-seed" experiments with wheat and *Arabidopsis*.

Key milestone:

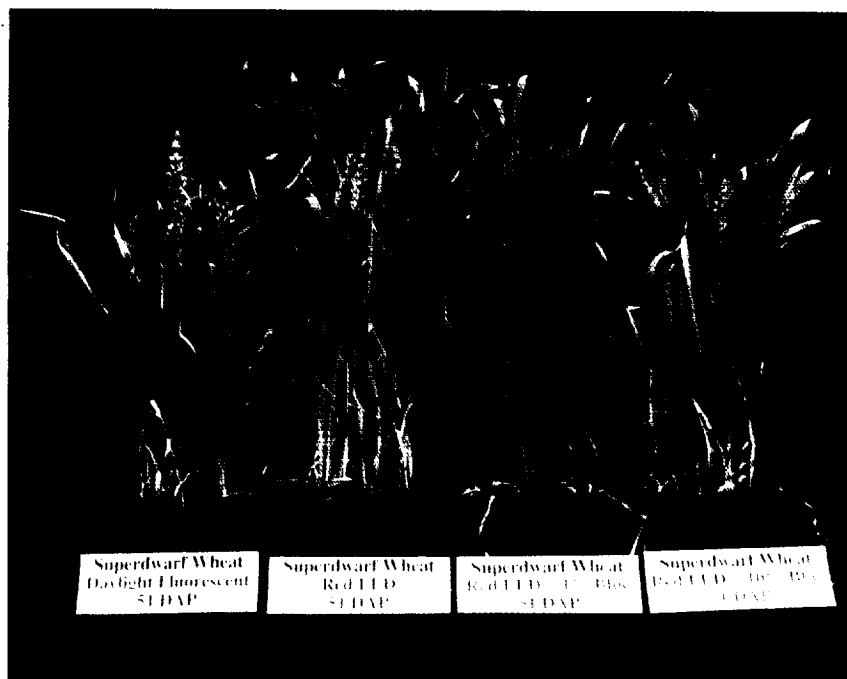
- 1995: Conduct carbohydrate metabolism studies and complete initial "seed-to-seed" experiments.

Contacts: W.M. Knott, Ph.D., and R.M. Wheeler, Ph.D., MD-RES, (407) 853-5142

Participating Organization: The Bionetics Corporation (C.S. Brown, Ph.D.)



Photosynthesis of Wheat Leaf Discs From Plants Grown Under Red LED's



Wheat Plants Grown Under White Light, Red LED's, or Red LED's Supplemented With 1 or 10 Percent Blue Light

Controlled Ecological Life Support System (CELSS) Engineering

The main purpose of the CELSS engineering group is to determine the engineering techniques and hardware required to successfully operate a CELSS. This includes maintaining the physical systems for biological research, performing engineering analysis of existing systems, and designing and testing new systems.

The engineering group studies CELSS operations both from a system standpoint and by looking at specific system components or processes. Current CELSS breadboard research focuses on biomass production (plant growth) and resource recovery (recycling of nutrients). Biological processes involved with CELSS operation are viewed in engineering terms (production rates, consumption rates, system reliability and maintainability, etc.) to determine the effect on the total system. In addition, performance of the physical components is constantly monitored with an eye on improvement. These efforts are documented in several reports and publications.

The CELSS engineering group also supports smaller experiments for the overall CELSS breadboard project, which range from simple monitoring of one environmental parameter to control of several experiment parameters; this includes experiments in CELSS and plant space biology.

Key accomplishments:

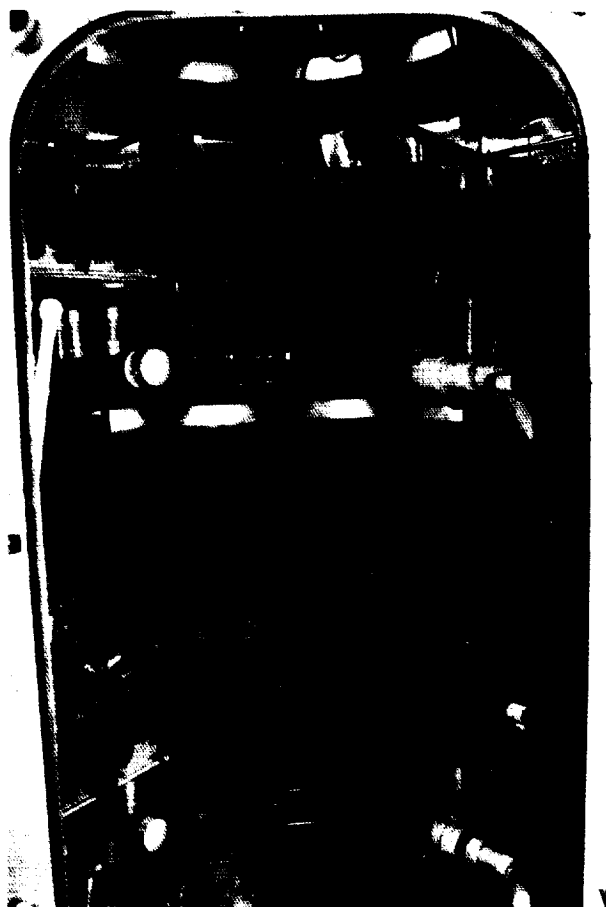
- 1988: First atmospherically closed operation of the Biomass Production Chamber (BPC).
- 1990: Metal halide lamps tested as a BPC lighting source.
- 1991: Atmospherically separated the two levels of the BPC. Installed a pressure compensation system in the upper BPC. Created the computer database to track physical reliability of the BPC.
- 1992: New environmental monitoring system computer installed. Completed the condensate recovery system. Installed a pressure compensation system on the lower level of the BPC and oxygen scrubbers to enable a long-term atmospheric closure of the BPC.
- 1993: Redesigned and installed a new environmental control system computer and hardware for the BPC.
- 1994: Integrated and operated the breadboard-scale aerobic bioreactor with the BPC for continuous recycling of plant nutrients. Redesigned and implemented the breadboard alarms. Operated the breadboard for a 6-month continuous period.

Key milestones:

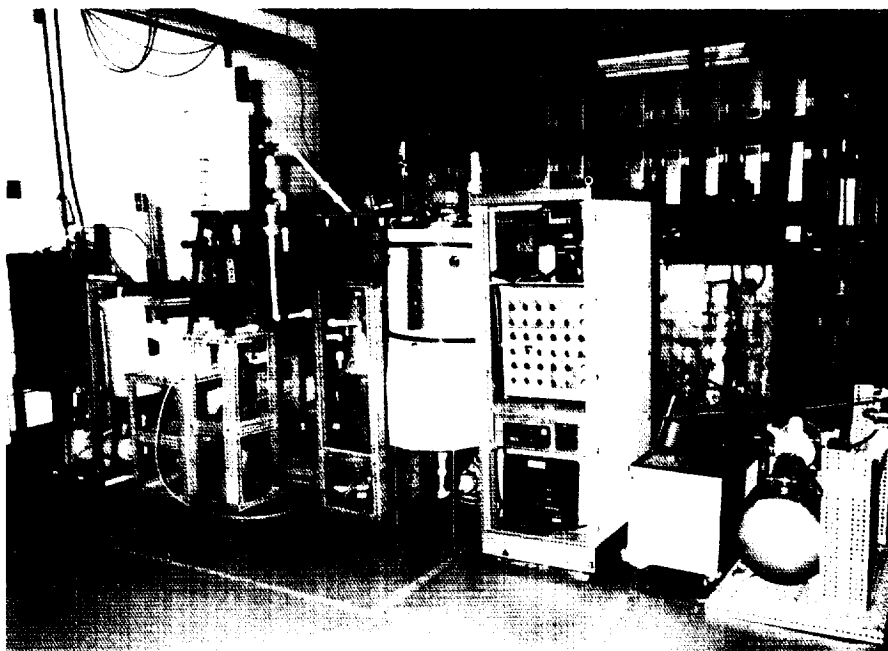
- 1995: Installation of the robotic arm for remote BPC operations. Twelve-month continuous operation of the breadboard. Perform mixed crop growth tests. Install stand-alone, mechanical backup controllers.
- 1996: One year continuous operation of the breadboard.

Contact: J.C. Sager, Ph.D., MD-RES, (407) 853-5142

Participating Organization: The Bionetics Corporation (R.E. Fortson)



Lettuce in the BPC



BSAB for Nutrient Recovery

Porous Tube Plant Nutrient Delivery System (PTPNDS)

The Microgravity Plant Nutrient Experiment (MPNE) is a Space Shuttle middeck locker hardware test of a concept conceived and developed at KSC. This experiment will verify the PTPNDS in microgravity. Efforts during the past year focused on the design of the flight hardware. A number of issues concerning various components of the payload were addressed. The candidate plants identified to include in the first space-flight verification test are wheat and lettuce. Plant seed cassettes for microgravity were designed and prototypes were built that incorporate previously flown seed holders. Initial determinations were made for the requirements for germination within these seed holders and will be translated to set points for infrared water availability sensors; the sensors have been designed and the prototypes have been built.

Video recording of plant development during the mission will be performed using an 8-millimeter charge coupled device (CCD) camera, mounted within the payload outside of the plant chamber. The red and blue light-emitting diodes (LED's) that will be used to light the plants have been shown to provide adequate light for photosynthesis and orientation for the given mission length. Fans will be used to bring in cabin air to cool electronic components and to circulate the air within the closed plant chamber.

The design is being finalized and fabrication of prototype components is nearly complete. The target date for the completion of the flight hardware is September 1995.

Key accomplishments:

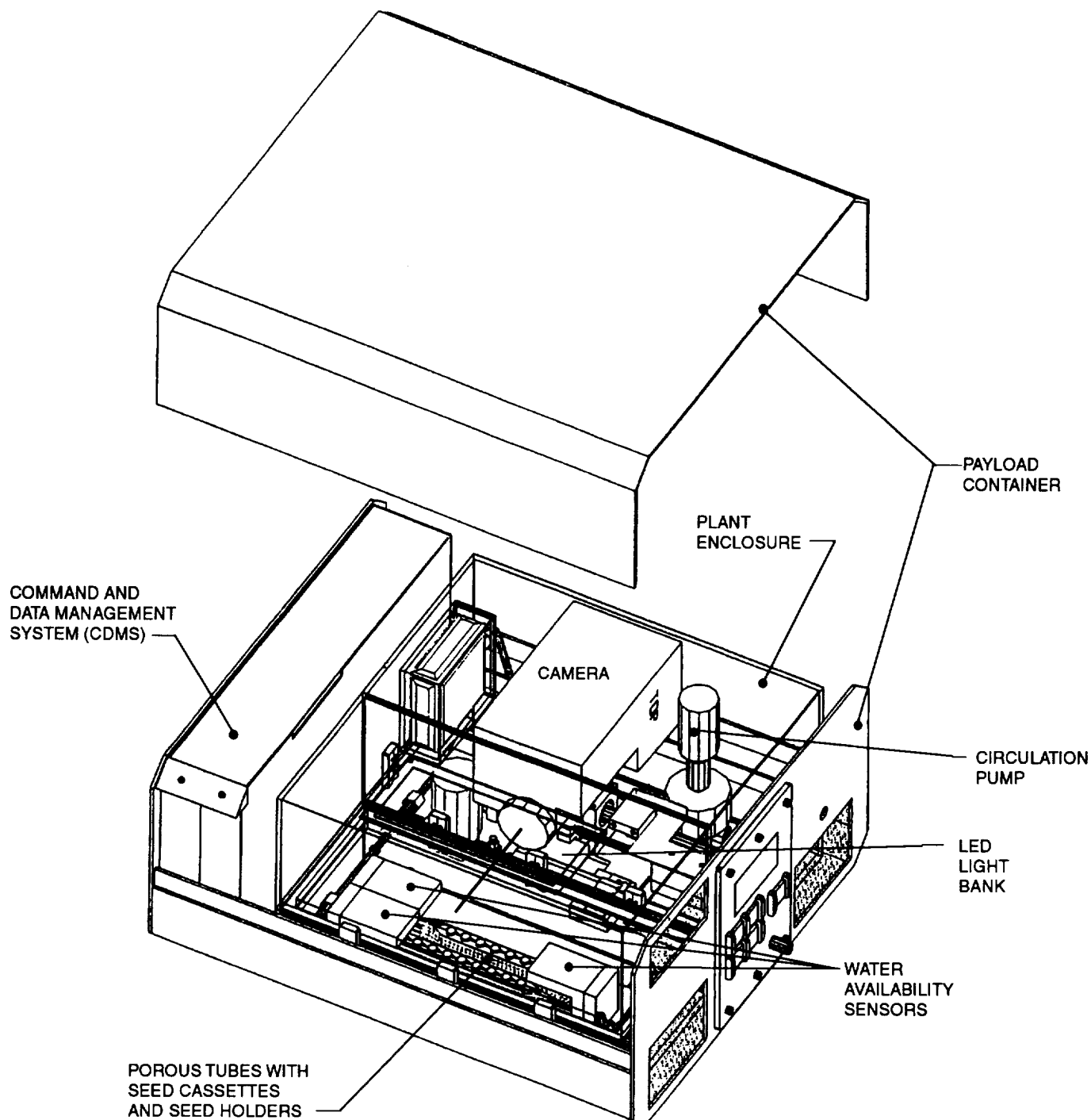
- Development and testing of the PTPNDS in a ground-based KSC laboratory with modifications and improvements that were incorporated over the past 9 years. System testing with wheat, beans, rice, soybeans, tomatoes, lettuce, radish, white potato, sweet potato, and *Arabidopsis* was performed.
- Miniaturization of the PTPNDS for applying the concept to Space Shuttle middeck hardware has been performed over the past 4 years.
- 1992: Development and testing of the KC-135 aircraft test bed units TBU's and initiation of laboratory studies in preparation for space flight.
- 1993: Design of space-flight hardware for the Space Shuttle middeck. Plant selection and germination, nutrient uptake, and plant lighting tests were performed.
- 1994: Finalized design. Construction of the prototype and space-flight hardware. Development of an experimental protocol for performing the hardware test on the Space Shuttle.

Key milestones:

- 1995: Testing of space-flight hardware on the KC-135 aircraft. Complete the construction and testing of space-flight hardware with final hardware and protocol.
- First quarter, 1996: Initial space-flight test.

Contacts: W.M. Knott, Ph.D., and J.C. Sager, Ph.D., MD-RES, (407) 853-5142

Participating Organization: The Bionetics Corporation (T.W. Dreschel and C.W. Carlson)



Microgravity Plant Nutrient Experiment

CELSS Biomass Production Research

In support of KSC's Controlled Ecological Life Support System (CELSS), ancillary plant studies provide information that aids in the development of production strategies for the Biomass Production Chamber (BPC) (see the article "CELSS Biomass Production Chamber").

Focus has been placed on using aerobic bioreactor technology for the extraction of plant nutrients from harvested inedible plant biomass, which is recycled back into the plant production system. Test crops grown in the recirculating hydroponic systems include lettuce, wheat, and potato. Depending on the nutrient recovery method, nitrogen may be recycled back to the nutrient solution as either $\text{NO}_3\text{-N}$ or $\text{NH}_4\text{-N}$. Mixed nitrogen solutions and their relative ratios can affect plant growth and development. Studies of various formulations and their effect on wheat and rice growth are being conducted. Information continues to be gathered on the hydroponic culture of peanut and tomato.

A nutrient recycling study using potato plants in a continuous production scenario resulted in hastened tuber development. It also appears that older potato plants may inhibit shoot growth of younger plants when sharing the same nutrient solution. It was seen that supply nitrogen in nutrient solutions at concentrations above 33-percent $\text{NH}_4\text{-N}$ reduced wheat yields. Rice is also being tested with a mixed nitrogen solution. Peanut and tomato cultivar selections are underway for use in future BPC studies.

Key accomplishments:

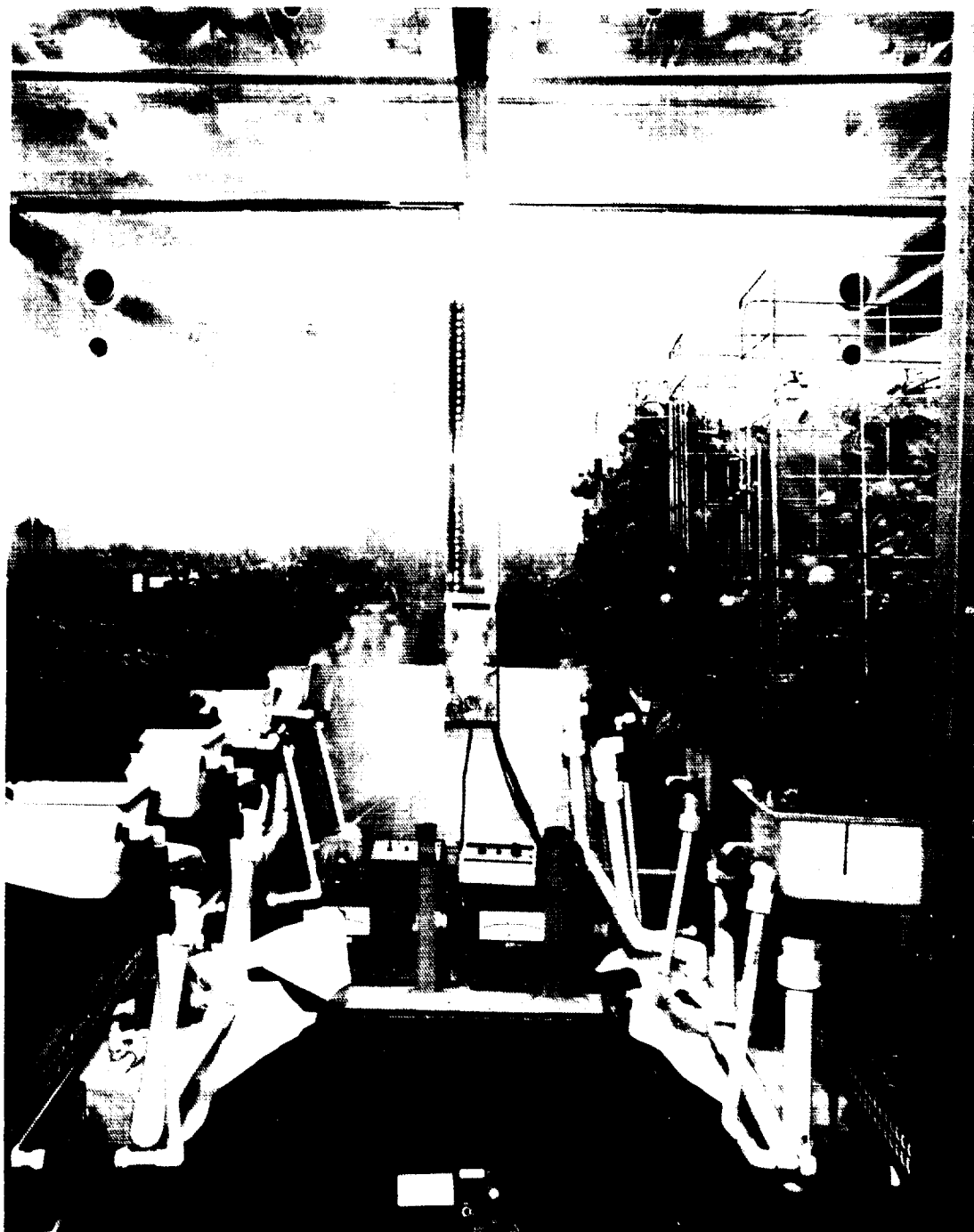
- 1990: Proximate composition of seed and biomass from soybean plants grown at different carbon dioxide concentrations was published as a NASA technical memorandum.
- 1991: Soybean stem growth under high-pressure sodium with supplemental blue lighting was published in the *Agronomy Journal*.
- 1992: Supraoptimal carbon dioxide effects on soybean growth and development in controlled environments were published in the *Journal of Plant Physiology*.
- 1993: Hydroponic crop production using recycled nutrients from inedible crop residues was published in the International Conference on Environmental Systems (ICES) and was the winner of the Arch T. Colwell Merit Award.
- 1994: Effect of mixed nitrogen sources on the growth and development of wheat was determined.

Key milestones:

- 1995: Optimize nutrient recycling by growing crops on nutrients recycled from a simulated human waste stream.
- 1996: Integrate the crop production subsystem with an aquaculture subsystem.
- 1997: Compare the efficiency of nutrients recovered from an aerobic process versus an anaerobic process.

Contact: R.M. Wheeler, MD-RES, (407) 853-5142

Participating Organization: The Bionetics Corporation (C.L. Mackowiak and G.W. Stutte)



Tomato Cultivar Comparison

Super Elevated CO₂ (SECO2) Experimental Plant Growth Chambers

The growth of plants in a microgravity environment, such as the Space Shuttle or the proposed Space Station, is challenging due to the peculiar environmental conditions found onboard orbiting spacecraft. Current and proposed chambers for growing plants in space are, by necessity, contained within the closed atmosphere of the orbiting space vehicle. Plants grown within these chambers can be expected to experience different atmospheric conditions due to human, mechanical, or environmental control system activities as well as normal plant growth and metabolism. A consistent problem is the necessity of either a sealed growth chamber atmosphere or a chamber atmosphere that is recirculated with spacecraft cabin air. In both cases, atmospheric carbon dioxide (CO₂) concentrations can fluctuate widely from subambient (<350 $\mu\text{mol}\cdot\text{mol}^{-1}$) to super-elevated levels of 10,000 to 50,000 $\mu\text{mol}\cdot\text{mol}^{-1}$. Plants are sensitive to changes in both major and minor components of the surrounding atmosphere. Fluctuations in oxygen, carbon dioxide, and humidity levels can affect the rates of photosynthesis and respiration, while minor organic constituents can either cause direct damage or alter plant response at the molecular level. An understanding of the effects of different atmospheric conditions, including exposure to super-elevated CO₂ concentrations on plant growth, morphology, and metabolism is necessary prior to determining the influence of gravity on these parameters.

The SECO2 series of ground-based studies in the Plant Space Biology Laboratory at KSC utilizes 38-liter polycarbonate chambers with atmospheric gas components monitored and controlled by custom software on a UNIX workstation. Both nutrient delivery and humidity control systems are based on the porous tube nutrient delivery system (PTNDS). Initial biological testing of the system has shown that growth of *Arabidopsis thaliana* at continuous elevated and super-elevated CO₂ levels affects the morphological development, starch and chlorophyll content, and enzymes in the carbon assimilation pathway.

Key accomplishments:

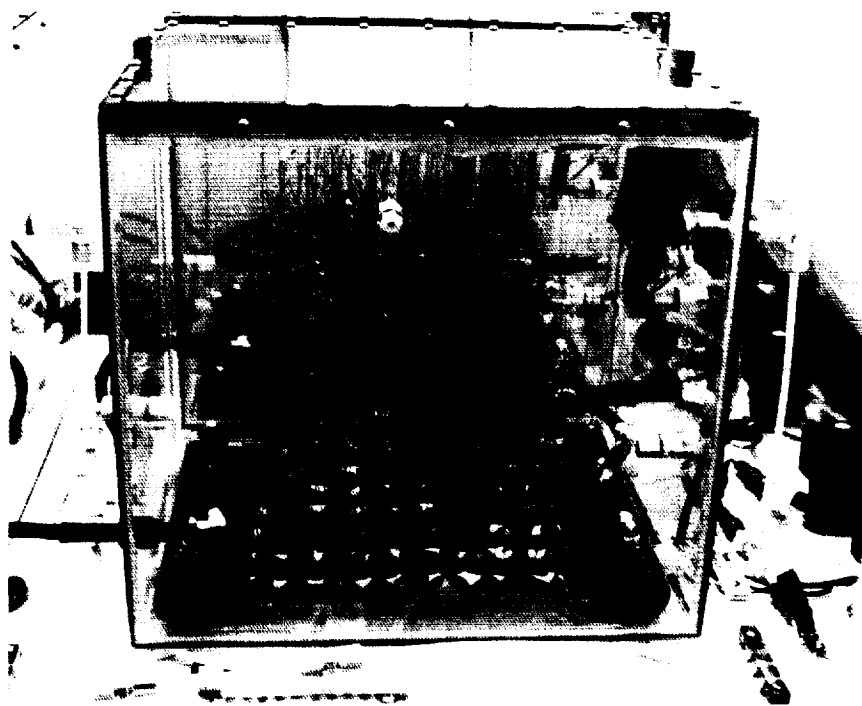
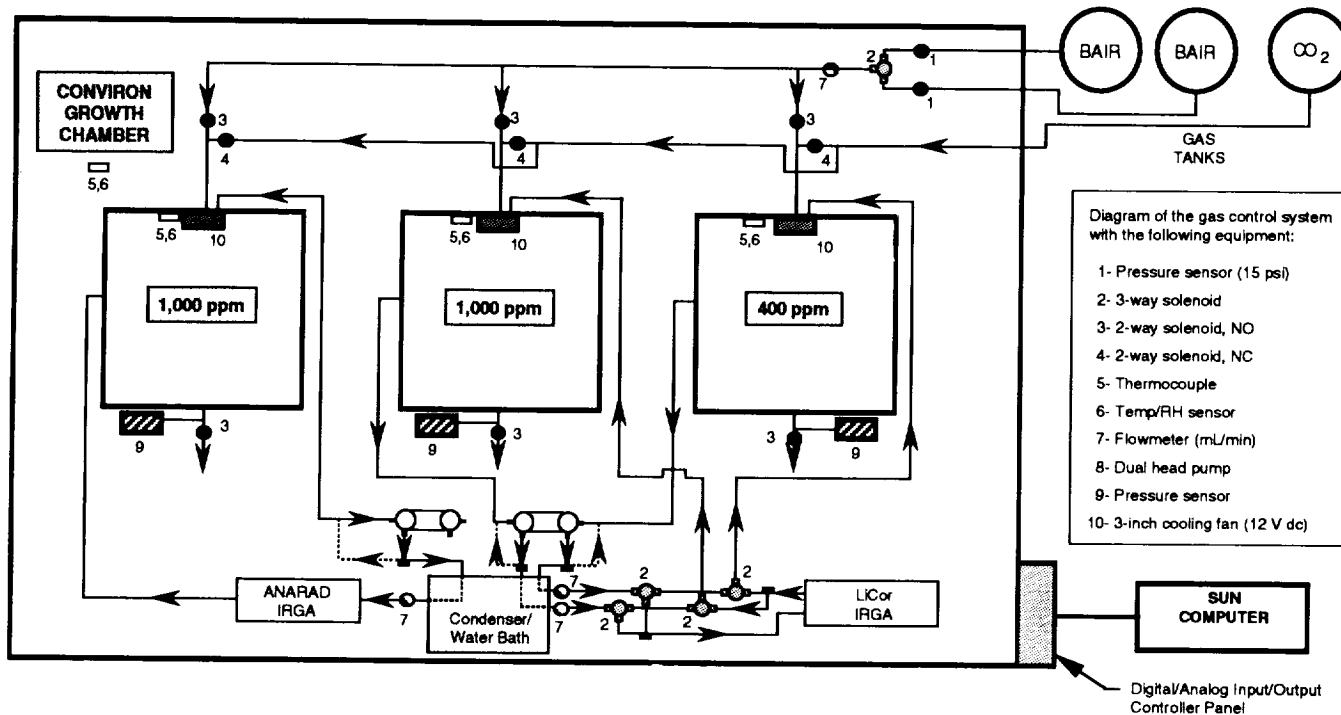
- 1993: Chamber hardware design and controlling computer software development.
- 1994: Chamber fabrication, control system integration, biological testing of system with four 30-day growth cycles of *Arabidopsis thaliana*, and installation of humidity control system.

Key milestones:

- 1995: Growth studies of *Arabidopsis thaliana* at elevated CO₂ levels with a controlled humidity. Initiation of water-stress experiments under elevated CO₂ conditions using transgenic *Arabidopsis thaliana* with molecular markers for indication of environmental stress.
- 1996: Continue elevated CO₂ experiments with *Arabidopsis thaliana* and Super Dwarf Wheat. Begin alternative lighting studies using light-emitting diodes in conjunction with various atmospheric conditions.

Contacts: W.M. Knott, Ph.D., and R.M. Wheeler, Ph.D., MD-RES, (407) 853-5142

Participating Organization: The Bionetics Corporation (W.C. Piastuch, Ph.D., and T.W. Dreschel)



Overview of SECO2 Chamber With Associated Hardware and Support Equipment



The Atmospheric Sciences program at the John F. Kennedy Space Center (KSC) addresses the impacts of weather on ground, launch, and landing processing with a view to increasing safety of personnel, protecting resources, and reducing lost work time by improving detection, analysis, and prediction of weather events and protection from weather events. Many of the weather impacts are of a specialized nature, differing from those felt by the public and even aircraft operations, and require studies and development that cross the lines of conventional scientific disciplines. Weather events focused upon by the program include lightning and cloud electrification, convective cloud growth, atmospheric surface and planetary boundary layer circulations and processes, wind shear effects, severe weather phenomena, rain, wind, and fog. Short-term attention is being directed to:

1. Mesoscale numerical weather prediction models
2. Numerical models for prediction of transport and diffusion of hazardous materials
3. Improvement and development of detection instrumentation and protection methods
4. Use of expert knowledge and artificial neural network techniques
5. Improvement of decisionmaking processes
6. Improvement of the processing and synthesizing of the voluminous data sets needed for accurate description of weather events and processes to effectively display the information and aid in its assimilation by weather forecasters and operations and safety decisionmakers

Long-term attention will be given to encouraging the evolution of more powerful numerical prediction models and computer systems, advanced detection and analysis of weather processes, advanced protection methods, and systems to support the processing and protection of future space vehicles and launch systems.

Atmospheric Sciences

Coordinated Approach to Mesoscale Numerical Weather Prediction

Sophisticated models, adequate high-resolution data, and affordable computer power are becoming available to attack two difficult weather prediction problems attending operations at KSC: thunderstorms and toxic diffusion. Three separate efforts are being integrated by the Applied Meteorology Unit (AMU). The AMU is a joint venture of NASA, the U.S. Air Force, and the National Weather Service, operated by ENSCO, Inc. This is the second year of a coherent multi-year approach to solve these problems.

The efforts are each derived from Small Business Innovation Research (SBIR) programs. The Mesoscale Atmospheric Simulation System (MASS) model from MESO, Inc., was delivered as the result of a NASA Phase II SBIR. The model is a three-dimensional, hydrostatic nested grid model with cloud physics. The smallest grid is 11 kilometers. It has the ability to continuously "nudge" the model forecasts with real data.

The Emergency Response Dosage Assessment System (ERDAS) model is a three-dimensional, nonhydrostatic nested grid model with toxic diffusion capability but without cloud physics. It was developed under an Air Force Phase II SBIR by Mission Research Corporation, ASTeR Division, and has a fine grid resolution of 3 kilometers.

The Parallelized Regional Atmospheric Modeling System (RAMS) Operational Weather Simulation System (PROWESS) is a three-dimensional, nonhydrostatic nested grid model based on the same model as ERDAS; but its fine grid resolution is 1.25 kilometers and includes cloud physics without toxic diffusion. It is a follow-on to a NASA Phase I SBIR and is currently under development by ASTeR, with NASA advanced development funding.

The AMU is evaluating and tailoring MASS for transition to operational forecast use and was tasked to evaluate ERDAS for operational support to hazardous operations beginning early in 1994. The AMU also supervises the PROWESS subcontract. Each model has advantages and weaknesses. The unified approach is expected to result in a single-operational, numerical weather prediction system on the 1.25-kilometer scale with both cloud physics and toxic diffusion. It will have most of the advantages of each of the three and few of their weaknesses.

Key accomplishments:

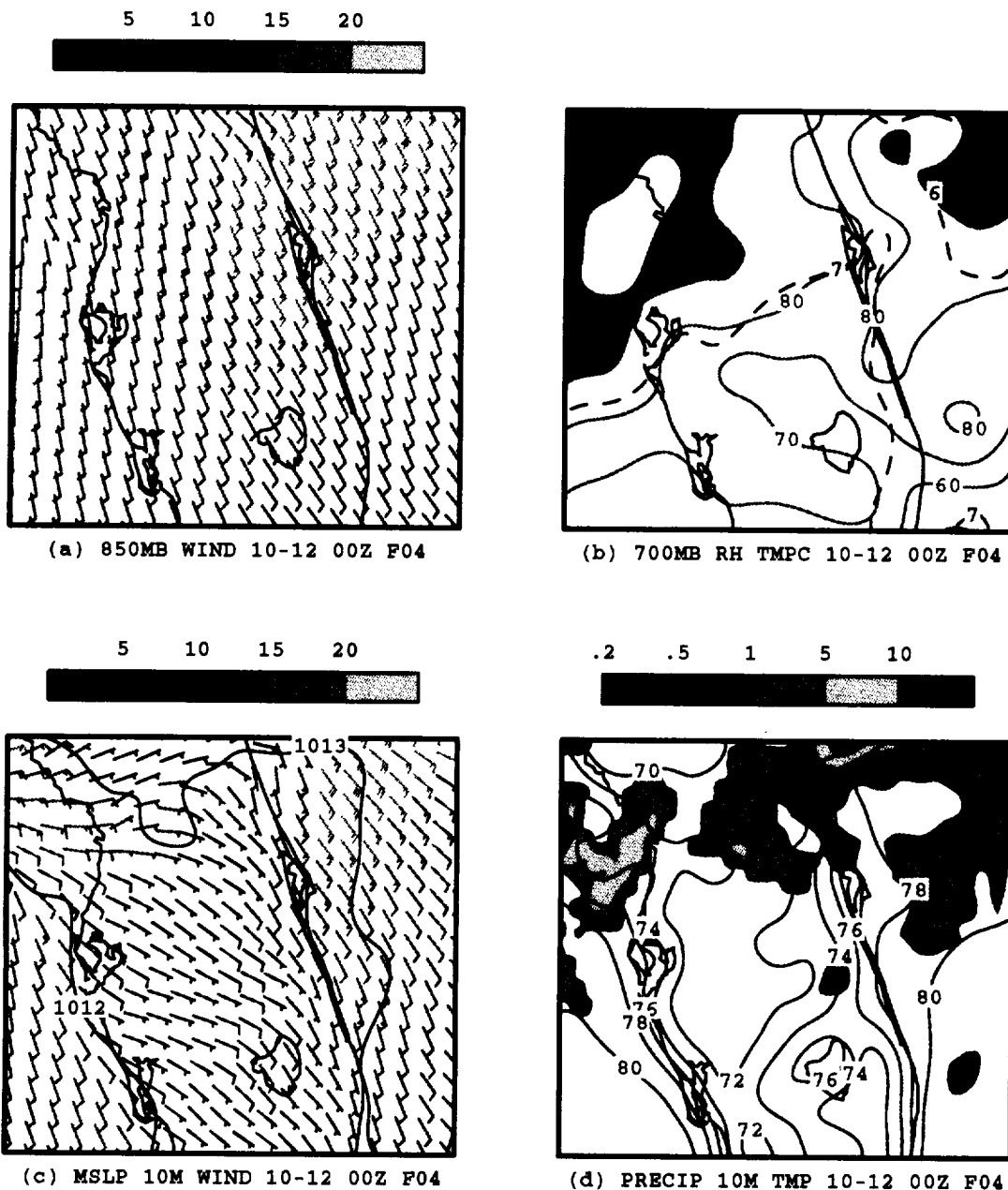
- 1991 to 1993: MASS and ERDAS models developed under SBIR contracts.
- 1993: MASS model delivered to AMU and configured to accept real-time data from meteorological data systems. PROWESS requirements specified and work begun.
- 1994: MASS and ERDAS models running in real-time operational configuration. PROWESS running on multiple parallel processors with MASS/ERDAS-compatible data formats.

Key milestones:

- 1995: Evaluate MASS and ERDAS accuracy and utility. Begin transition planning. Complete PROWESS prototype and preliminary evaluation. Deliver to AMU for detailed evaluation.

Contact: *F.J. Merceret, Ph.D., TM-LLP-3, (407) 867-2666*

Participating Organizations: *ENSCO, Inc. (R. Evans; J. Manobianco, Ph.D.; A. Yarsavich; and G. Taylor, Ph.D.); MESO, Inc. (J. Zack, Ph.D.); and Mission Research Corporation, ASTeR Division (W. Lyons, Ph.D.)*



The figure shows simulated fields from a three-dimensional regional scale model at 1600 Universal Coordinated Time (UTC), 12 September 1994, over most of the Florida peninsula. Panel (a) displays wind barbs that are shaded according to wind speed (knots) at an altitude of roughly 1.5 kilometers. Panel (b) shows relative humidity (percent) and temperature (degrees Celsius) at an altitude of about 3 kilometers. Relative humidity greater than 90 percent is shaded in panel (b). Panel (c) depicts wind barbs shaded according to wind speed (knots) at 10 meters above the surface and sea level pressure (millibars). Panel (d) shows temperature (degrees Fahrenheit) at 10 meters above the surface and 1-hour accumulated precipitation (millimeters per hour) shaded according to intensity. The wind barbs in panels (a) and (c) also indicate the direction of wind flow.

**MUSIC Thunderstorm Location From Spatio-Temporal Electric Field-
Mill Data — Phase II SBIR**

KSC has the ability to detect precipitation, lightning, and electrical fields that indicate threats to both ground and launch operations. The forecaster is inundated with so much information it does not have the time to use it all effectively. KSC needs improved methods that integrate, automate, and advise the forecaster of operational threats. Scientific Applications and Research Associates, Inc., has a Phase II Small Business Innovation Research (SBIR) contract to provide a thunderstorm workstation that will track storm centers based on electric field data, animate the storm tracks, establish system errors, and provide information on the storm phase. The system is also very user friendly.

SARA, Inc., has implemented two analysis techniques for identifying storm centers based on electric field data. The first approach is based on Multiple Signal Characterization (MUSIC) eigenanalysis. This technique utilizes a model of the thunderstorm and calculates model parameters while efficiently searching the entire parameter space. SARA, Inc., has also implemented a least squares algorithm which utilizes the same thunderstorm model as the MUSIC algorithm but only searches a subset of the model space. The storm centers are displayed in color and looped to depict storm movement.

SARA, Inc., has completed Phase I and demonstrated system feasibility. A workstation with installed applications has been received at KSC for review and user feedback. Applications include the capability to model thunderstorm charge distribution using both MUSIC and least squares techniques and the development of an error estimate. The contractor can simulate and replay thunderstorms to demonstrate system functionality and to test the user interface. Future plans include validation of all applications and a model assessment.

Key accomplishments:

- Established the feasibility of thunderstorm localization and tracking using MUSIC techniques.
- Developed the application software that estimates spatial location errors based on the geometry of the network of sensors.
- Delivered the workstation to KSC for evaluation.

Key milestones:

- January 1995: Validate the application software.
- April 1995: Deliver the Phase II report.

Contacts: L.M. Maier, TE-ISD-3A, (407) 867-4409; S.S. Largent, OP-SCO-1, (407) 867-2309; and F.J. Merceret, TM-LLP-3, (407) 853-8200

Participating Organizations: EG&G Florida, Inc. (L.L. Albright) and Scientific Applications and Research Associates, Inc. (J.T. Robinson)



Sensor System To Monitor Cloud-to-Stratosphere Electrical Discharges

Work under Phase I of this effort documented over 600 examples of optical flashes above thunderstorms that span the stratosphere. Phase II of this project will develop a sensor system for monitoring cloud-to-stratosphere electrical discharges.

The task is to detect the unique electrical discharges (call sprites) and correlate their occurrence with cloud characteristics and radio frequency emissions. The technical approach was to use special low-light cameras at two or more locations to detect and characterize the events. The cameras were supplemented by extremely low frequency (ELF) and very low frequency (VLF) receivers and by instruments for determination of the spectrum of the light emissions.

Key accomplishments:

- 1994: Phase I project completed.
- April 25, 1994: Phase II started.
- June 25 to September 20, 1994: Summer field work.

Key milestones:

- December 1994: Project video.
- July to September 1995: Florida field program.
- December 1995: Project video.
- March 1996: Final report.

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The Materials Science Technology program at the John F. Kennedy Space Center (KSC) supports advanced technologies directed toward improving launch site safety, operability, and maintainability. The program includes application materials engineering, materials testing, chemistry, and other science disciplines. The near-term program focuses on Shuttle ground processing improvement by providing materials and coatings that afford better corrosion control, materials with better hazardous systems compatibility, and improved testing methods and instrumentation. The long-term program will investigate materials technology that can be used to develop new launch and processing facilities for future vehicles and payloads, will reduce the cost of maintenance, will provide higher safety and reliability, and will provide more environmentally compatible systems.

Materials Science

Environmentally Compliant Coating Systems for the Shuttle Launch Sites

In recent years, environmental regulations have sought to restrict the use of paints and coatings containing high concentrations of solvent. The use of the solvent-based, inorganic, zinc-rich primers currently tested and approved could be prohibited at KSC in the near future due to their volatile organic content (VOC) levels. These materials all have VOC levels of 450 grams per liter (3.75 pounds per gallon), whereas the maximum levels allowed in some areas (such as California, certain counties in Florida, and many other urban areas of the United States) are 420 grams per liter (3.5 pounds per gallon) or lower. Legislation has dictated this level be reduced to 350 grams per liter (2.8 pounds per gallon). Therefore, the possibility is very real the inorganic, zinc-rich primers and topcoat systems presently approved at KSC will be prohibited and unavailable for use.

In response to this circumstance, the current study has been expanded to search for inorganic, zinc-rich coatings and topcoat systems that provide superior protection to KSC launch structures and ground support equipment and that fully comply with environmental regulations. Currently, the protective coating manufacturing industry is producing environmentally compliant, inorganic zinc coatings such as high-volume solids and water-based systems. New topcoat systems are also being developed to conform to the anticipated strengthening of environmental air quality standards.

The application of these environmentally compliant coating systems was completed in April 1991, and the test panels were exposed in May 1991 to atmospheric contaminants at the KSC beach corrosion site with concurrent applications of an acid slurry to simulate the conditions experienced at the launch site. The results of the 18-month exposure and the laboratory data have been compiled in a report available under document number FAM-93-2004. The results of this testing have identified many environmentally compliant coating systems to be used on KSC launch structures and ground support equipment. The successful coating materials have been included on the Approved Products List contained in KSC-STD-C-0001. The panels are currently nearing the 40-month evaluation point and a status report detailing the 36-month exposure results will be prepared.

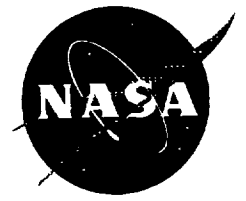
Key accomplishments:

- Successfully applied the environmentally compliant coating systems to over 300 test panels and exposed them at the KSC beach corrosion test site for 40 months.
- Conducted laboratory tests on the zinc primers to determine heat resistance and the level of adhesion to carbon steel.
- Evaluated the coating systems at the 18-month point and prepared a report detailing the beach exposure and laboratory data.

Key milestones:

- Continue to monitor the test panels for the required 5-year exposure period and apply the acid slurry at regular intervals to simulate launch site conditions.
- Produce a status report at the 36-month point and a final report at the end of the 60-month exposure period to document the performance of the coating systems.
- Continue to monitor the state of the art in environmentally compliant coating technology and evaluate new products as required.

Contact: *L.G. MacDowell, DM-MSL-1M, (407) 867-3400*



KSC Corrosion Test Site

Accelerated Testing of Inorganic, Zinc-Rich Primers

Inorganic, zinc-rich coatings are used for corrosion protection of carbon steel structures at KSC. To be considered for use at KSC, a primer must successfully withstand exposure at the beach corrosion test site. Primers are periodically rated for rusting on a scale of 1 to 10 in accordance with ASTM D610, with a rating of 10 being the best. For preliminary approval, primers must achieve a rating of 9 or better after 18 months of exposure and continue to provide this level of protection for 60 months for final approval. Unfortunately, this process requires a considerable amount of time to place new products on the KSC Approved Products List contained in KSC-STD-C-0001.

Alternating current impedance measurement techniques, also known as electrochemical impedance spectroscopy (EIS), are being studied as a possible method for determining the corrosion resistance of inorganic, zinc-rich primers before exposing them to long-term testing at the beach corrosion test site. A reliable accelerated laboratory test method such as EIS could save time for preliminary approval of primers.

For this method, primers are sprayed on test panels for use in the laboratory experiments. The test panels are exposed at the beach corrosion site for various intervals before being brought back to the laboratory for testing. The panels are immersed in a 3.55-percent sodium chloride solution that is aerated during the test to provide the oxygen necessary for corrosion reactions. Test results have yielded trends between several EIS measurement parameters and atmospheric coating performance. Measurements of the change of polarization resistance, pore resistance, phase angle, and coating capacitance can be used to gain understanding of the complex behavior of these materials. By aging the coatings in a natural atmospheric exposure prior to laboratory testing, a correlation has been found between the experimental results and the long-term field results.

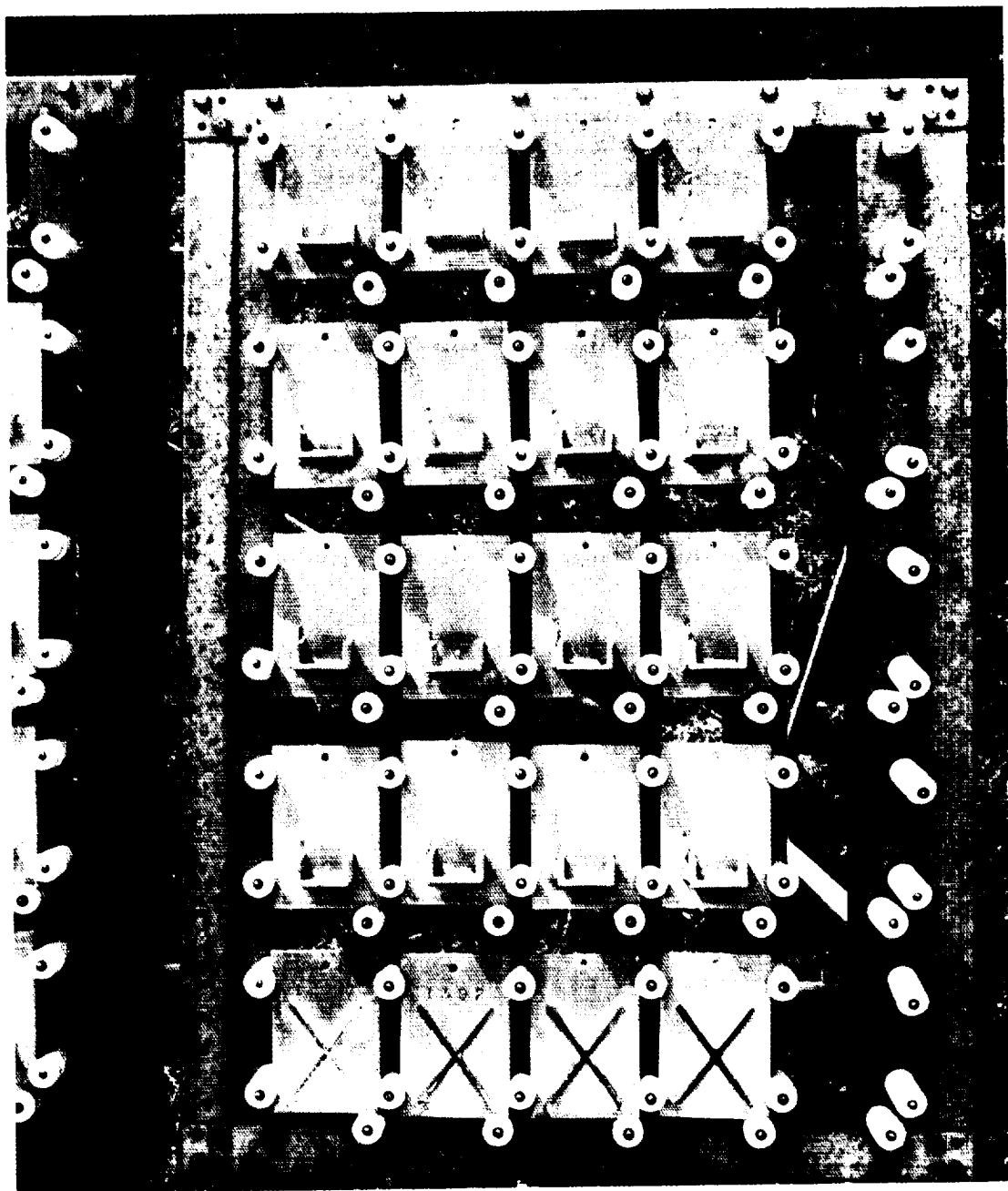
Key accomplishments:

- Test program was started in July 1993.
- Testing was conducted on primers that have already been exposed at the beach corrosion site for 40 months.
- Results were compared to similar work conducted in 1989.
- Completed the 12-month exposure period and analyzed the results.

Key milestones:

- Results will be compared to actual long-term field data for possible correlation.
- Data analysis techniques will be refined to allow predictive results based solely on EIS experiments.

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Exposure Testing at the KSC Corrosion Test Site

Repair of Deteriorating Steel-Reinforced Concrete

Steel-reinforced concrete is one of the best engineered composite materials; steel and concrete are not only complementary but also compatible. However, contamination of concrete with salt during service causes steel to corrode and, eventually, to be separated from the concrete.

The approach of injecting a corrosion-inhibiting chemical into a deteriorating concrete structure was studied. Ammonium quaternary salts, initially tested at SRI International, were selected. Laboratory tests showed promising results. The inhibitor injection was done by applying an electric field to expedite the migration of the inhibiting chemical. However, certain structures do not allow the use of the electromigration approach.

Future plans include a study of the migration behavior in the absence of an electric field, assisted by the capillary action of cracks (a deteriorating concrete structure should have some cracks). Also, the duration of the corrosion-inhibiting effect after treatment and side effects of such chemicals on concrete, if any, will be studied.

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| 12a. DISTRIBUTION / AVAILABILITY STATEMENT Unclassified - Unlimited Subject Category 99 | | | 12b. DISTRIBUTION CODE | |
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